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Arctic Ship Technology: The State of the Art – 1986

Summary Report

Prepared for
Transportation
Development Centre
Transport Canada

by
Melville Shipping Ltd.

MARCH 1987

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The State Of The Art - 1986

SUMMARY REPORT

Prepared
For

Transportation Development Centre
Montreal, Quebec

By

Melville Shipping Ltd.
Ottawa, Ontario

In Association with

Arctec Canada Limited
Canarctic Shipping Company Limited

March 1987

DISCLAIMER

The contents of this report reflect the views of the authors and not necessarily the official views or opinions of the Transportation Development Centre of Transport Canada.

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17. Abstract

This report presents the results of a review of Arctic ship technology. The objective of this review was to document the present state of the art in this field to provide ship designers and operators with a reference manual offering an up-to-date view of how the technology has developed over the last several decades.

A thorough literature search was conducted to identify relevant publications, technical reports and papers. The data obtained from this literature search was used as the basis for the state of the art review. The review is organized into the following subject areas: a) existing icebreaking ships; b) environment: ice, sea and meteorological conditions; c) ship operation: safety, navigation and communications; and, d) ship design: ship structure, hull, propulsion equipment, general outfit and auxiliary systems. The technology review is used, together with the results of a study on future Arctic shipping systems, to develop a programme of recommended research designed to address identified deficiencies.

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17. Résumé

Ce rapport présente les résultats du tour d'horizon sur la technologie des navires de cote arctique, dont l'objectif a été de mettre en évidence les connaissances acquises dans ce domaine et de fournir aux concepteurs et aux armateurs un ouvrage de référence sur l'évolution des techniques au cours des dernières décennies.

Une recherche documentaire exhaustive a été faite en vue de répertorier les ouvrages, rapports et mémoires traitant de ce domaine. Le contenu des ouvrages cités dans la bibliographie a servi de base au tour d'horizon. Les résultats sont organisés comme suit: a) brise-glace actuels; b) environnement glaciel, marin et météorologique; c) exploitation: sécurité, navigation et communications; d) conception: structures, coques, appareil propulsif, aménagements et systèmes auxiliaires. Ce tour d'horizon ainsi que le résultat de l'étude sur les systèmes de navigation arctique du futur doivent servir à l'élaboration du programme des recherches à lancer dans le but de combler les lacunes mises en évidence.

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1. INTRODUCTION

A review of the state-of-the-art of Arctic ship technology was commissioned in 1985 by Transport Canada's Transportation Development Centre (TDC) and has been co-sponsored by Canarctic Shipping Company Limited (Canarctic) and Melville Shipping Ltd. (Melville). The project was the responsibility of Melville, with assistance from Canarctic in the areas of Environment and Operations, and from Arctec Canada Limited (Arctec) in the areas of Structures and Performance Prediction.

The review was directed at those ship designers, ship operators, and regulators who are involved in the planning and developement of Arctic shipping projects. A report has been prepared entitled "Arctic Ship Technology - The State of the Art - 1986" (TP8094). The report is in two volumes; volume one contains the main text and volume two the bibliography. A separate report entitled "Probable Arctic Shipping Scenarios" by Melville, 198[illegible] TP6555) identifies the shipping projects which may occur in the Arctic and provides a focus for the technology review.

The summary report condenses the discussion of each major aspect of Arctic Ship Technology, reviewed in volume one of the main report, into a concise stand alone presentation. The important figures and tables have been retained for clarity as have the conclusions as to information deficiencies and required research.

2. EXISTING ICEBREAKING SHIPS

2.1 Introduction

A review of icebreaking technology can use the ships which have been built as a base against which innovative designs or operating proposals may be compared and assessed. The danger is that by accepting too rigidly the status quo, innovation will be discouraged. Ideally, innovation should spring from a full understanding of past experience.

While icebreakers and icebreaking cargo ships have a long history, the Wind Class vessels, which were built in the mid 1940's, are used here as a starting point. While interesting developments did occur before that time, few are having an impact on today's understanding of the technology.

Data has been compiled for icebreakers and icebreaking cargo ships from the following countries:

- Argentina
- Canada
- Denmark
- Finland
- Japan
- Sweden
- United Kingdom
- U.S.S.R.
- U.S.A.
- West Germany

The data presented in this section should only be taken as an illustration of what has already been constructed, not as limits to the present design, construction or operational capability.

2.2 Dimensions

The main dimensions of each icebreaker are plotted in Figure 2.2.1. The figure shows breadth, depth, and draft against length. The relationships are seen to be quite linear.

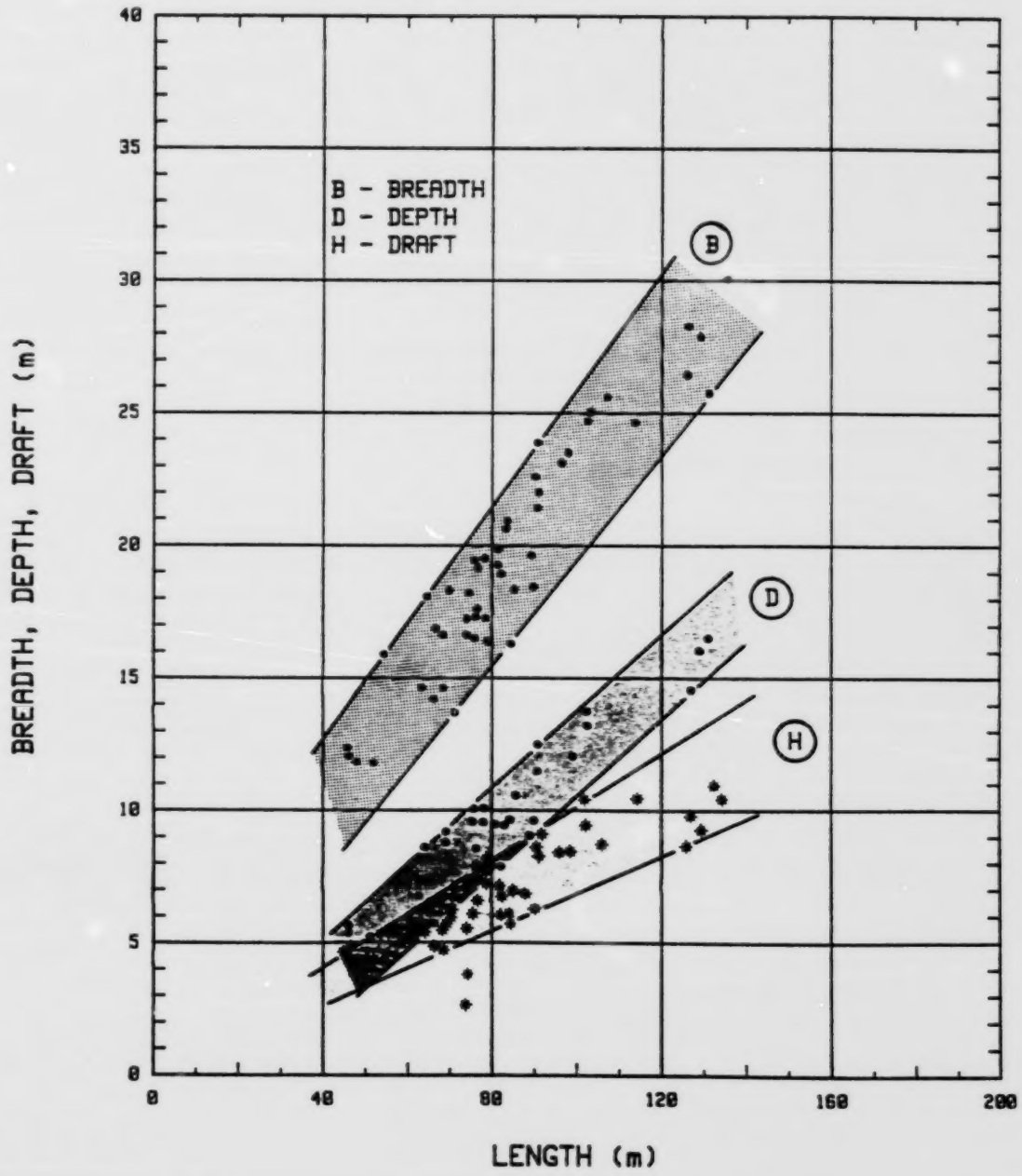
2.3 Hull Form

Hull forms have changed in several ways over the last 40 years. While few real trends can be detected, many design changes/innovations have been adopted, including;

- Straight stem
- Concave stem (White bow)
- Spoon bow with extended beam

FIGURE 2.2.1

ICEBREAKER DIMENSIONS



Note : Cargo ships are not included

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- Spoon/chine bow
- Flat family bow
- Thyssen/Waas bow
- Melville bow

The progression of design improvements has led to a steadily increasing understanding of the hull form parameters which are important to ship resistance in ice.

The more traditional way of assessing the shape of an icebreaking bow is to consider; the fineness (cb, block coefficient foreward of the waterline shoulder), the stem angle, or the Kashteljan and Shimanski coefficients (which combine the flare and waterline entrance angles for the whole bow). More recently, it has been recognised that it is not only the combination of flare and waterline angles which is important but also the location on the bow of these angles. The growing understanding of 'cusp patterns' and their importance to resistance has lead to attempts to design for particular cusp patterns.

The stern shape has experienced very few radical changes. Until the late 1970's, when the Beaufort Sea ice management ships began to introduce some unique features, the stern shape of icebreakers used the conventional open water ship configuration. This shape depends on the number of propellers, and may have an ice horn to protect the rudder.

2.4 Power and Performance

The propulsion characteristics of these icebreakers or icebreaking cargo ships has yielded information on the relationship between power and ship size, and between power and performance in level ice. Power versus breadth has been plotted in Figure 2.4.1 and bollard pull/breadth versus ice thickness in Figure 2.4.2

The power versus breadth data shown in Figure 2.4.1 demonstrates the trend of increase of power as a function of breadth. With the exception of the TERRY FOX class, the POLAR class vessels, and the Soviet Lash vessel, there is a fairly well defined relationship between power and breadth for previously constructed vessels.

The bollard pull/breadth versus ice thickness data shown in Figure 2.4.2 has been produced from information on the known performance of these ships in ice. A speed of 2 knots was chosen to normalise the data since below this speed the vessels may not be able to sustain continuous progress.

Interpretation of this data is made uncertain by the lack of documented evidence on the performance of many ships. Notwithstanding this uncertainty, it is apparent that a fairly well defined relationship exists between bollard pull/breadth and the ice thickness which may be broken at 2

FIGURE 2.4.1

ICEBREAKER POWER VERSUS BREADTH

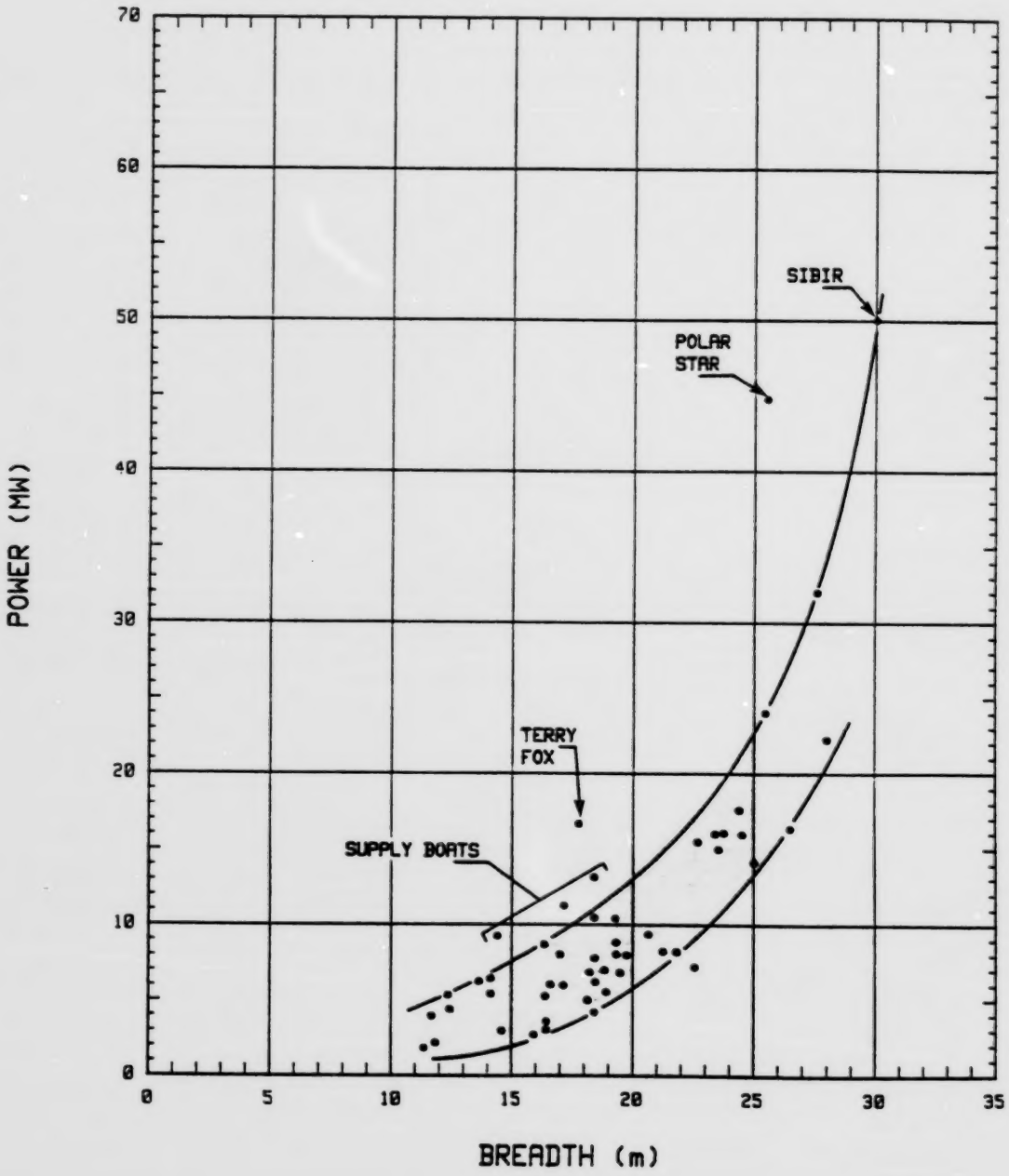

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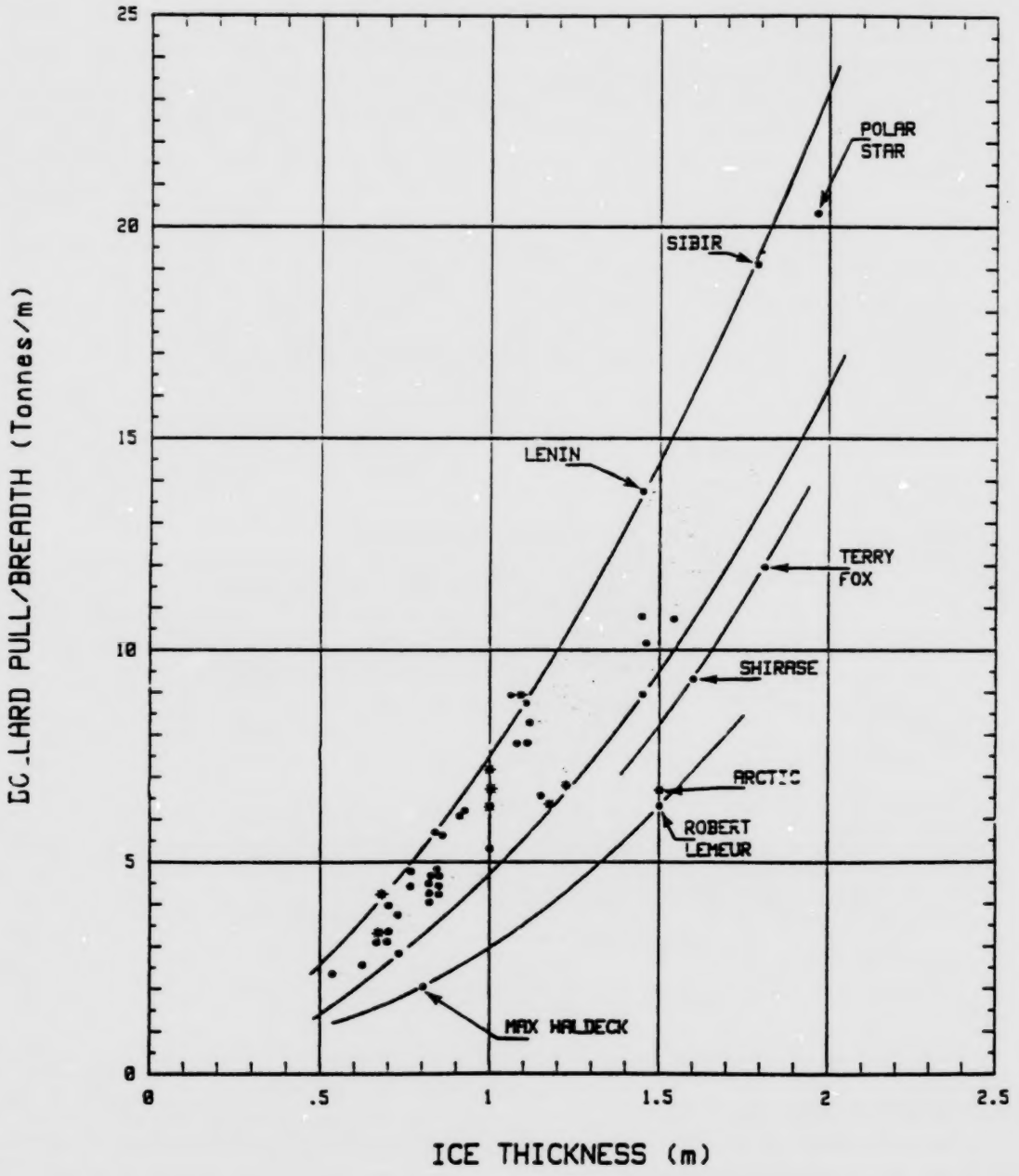
FIGURE 2.4.2

ICEBREAKING PERFORMANCE
BOLLARD PULL/BREADTH VERSUS ICE THICKNESS



Bollard pull is measured or calculated.
Data is adjusted for a 2 knot ship speed.

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knots. The range shown in Figure 2.4.2 seems to represent the gain in performance which may be expected from improvements in hull shape. It can be seen that the most recent ships have more efficient hull forms.

3. ENVIRONMENT

3.1 Introduction

The Arctic environment imposes limits on hull form and strength, powering requirements, operations, maneouvring and on bunkering and hotel arrangements. The severity of the Arctic environment varies seasonally and also from year to year, and this must be considered when selecting values to guide ship design.

3.2 Ice

Sea ice and glacial ice occur throughout the Arctic and will have a major effect on the viability of shipping systems in that area. This section summarieses the discussion of sea and glacial ice and of the incidence, dynamics and importance of these ice types in specific Arctic areas.

3.2.1 Glacial Ice

Some Arctic marine areas are subject to incursion from pieces of floating glacier ice. These are classified by size as ice islands, icebergs, bergy bits, and growlers (AES, 1980). Statistics on the frequency of occurrence of icebergs are not very reliable because of the difficulty of accurate counts over such a large area. Relative frequency, based on observation by the International Ice Patrol (1948-1978), are shown in Figure 3.2.1 (Arctec, 1983).

3.2.2 Sea Ice

Several types of sea ice occur in the Canadian Arctic, distinguished on the basis of age. The main subdivisions are first year ice and old ice.

First year ice is ice from a few millimetres to about 2 metres in thickness, which forms and melts completely within one annual cycle (generally October through September). When an ice floe or sheet does not melt entirely from one year to the next it is termed second year ice and in subsequent years, multi-year ice. Second and multi-year ice are in practice difficult to distinguish and are therefore alternately described as old ice (Markham, 1981).

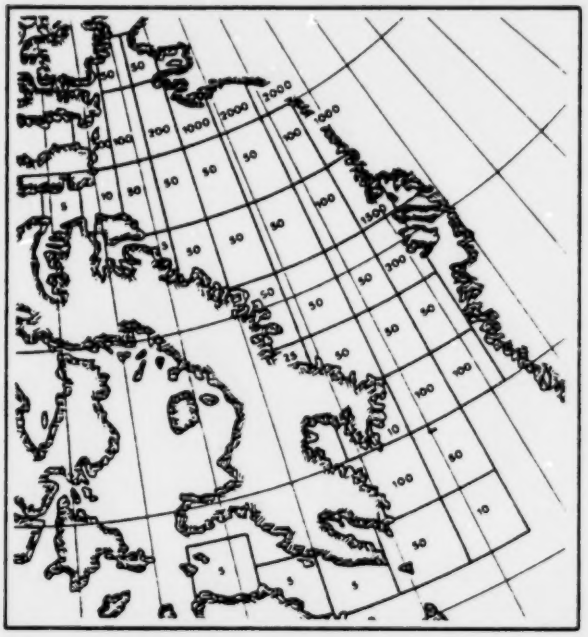
Patterns of occurrence of first year and old ice vary from year to year but can be characterized over the long term. Figure 3.2.2 shows the median concentration of all ice, based on about 20 years of record, for September and March (Markham, 1981). These are the months of minimum and maximum ice cover at most locations in the Arctic. Figure 3.2.3 show the median concentration of old ice (Arctec, 1985).

3.2.3 Shipping Oriented Geographic Review

While the statistics of the occurrence of various environmental features are of interest, it is mainly the dynamics and make-up of the ice cover in specific areas which is of most importance to ship operators. The

FIGURE 3.2.1

ICEBERG POPULATION
BAFFIN BAY AND DAVIS STRAIT



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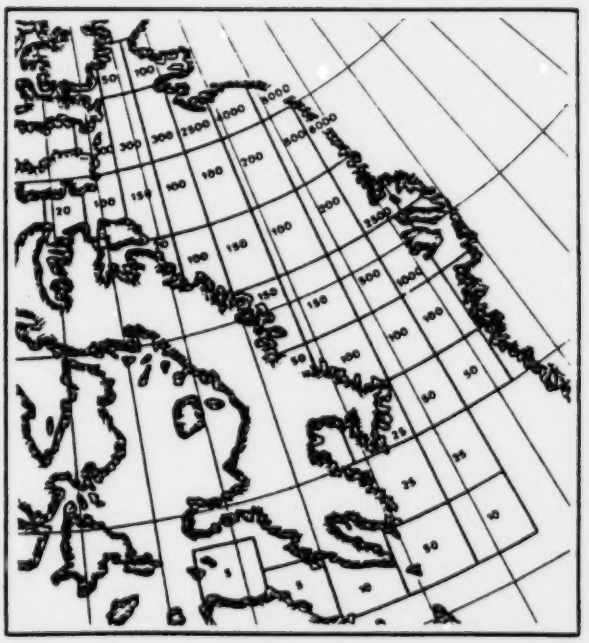

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ESTIMATED POPULATION
IN 2° x 4° ZONE OF
ICEBERGS > 100 m DIA

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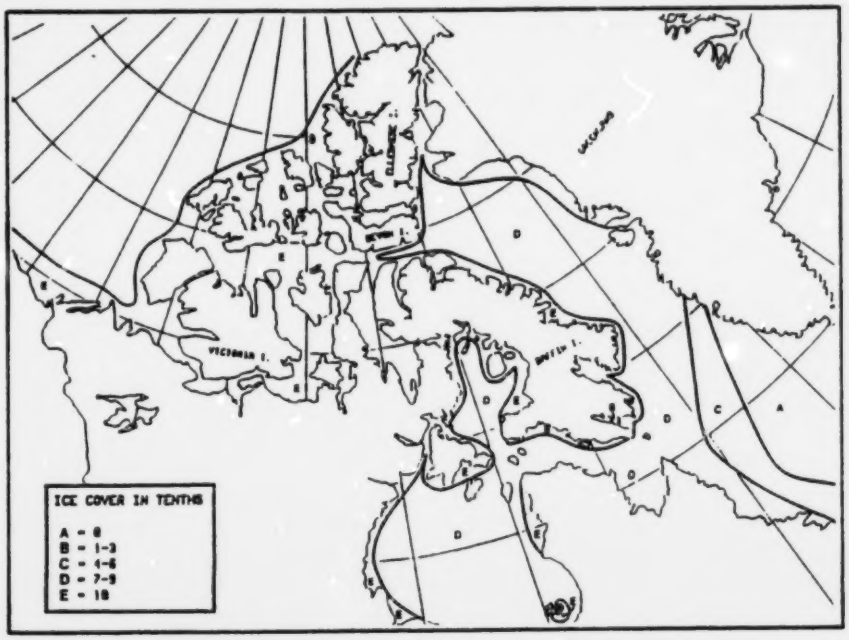
FIGURE 3.2.2

MEDIAN SEA ICE CONCENTRATION



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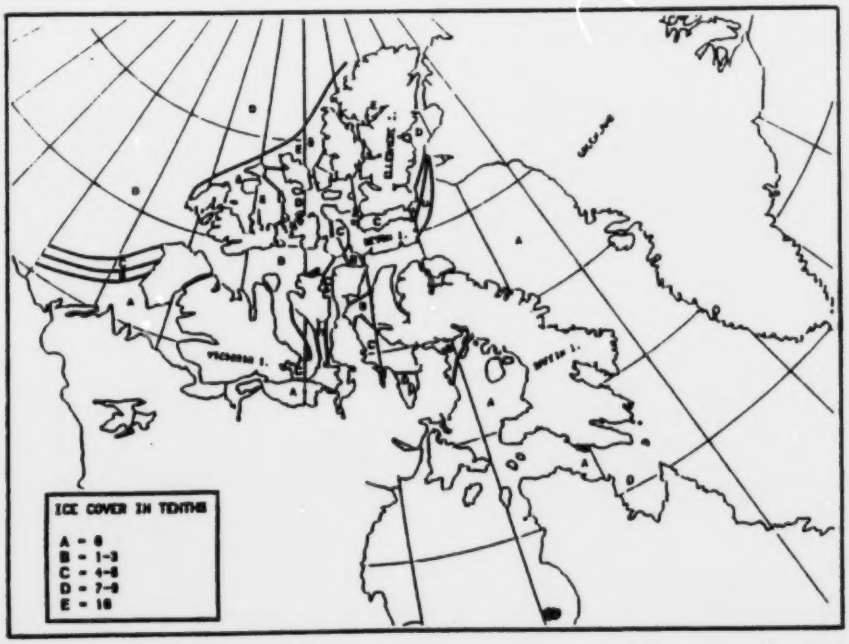

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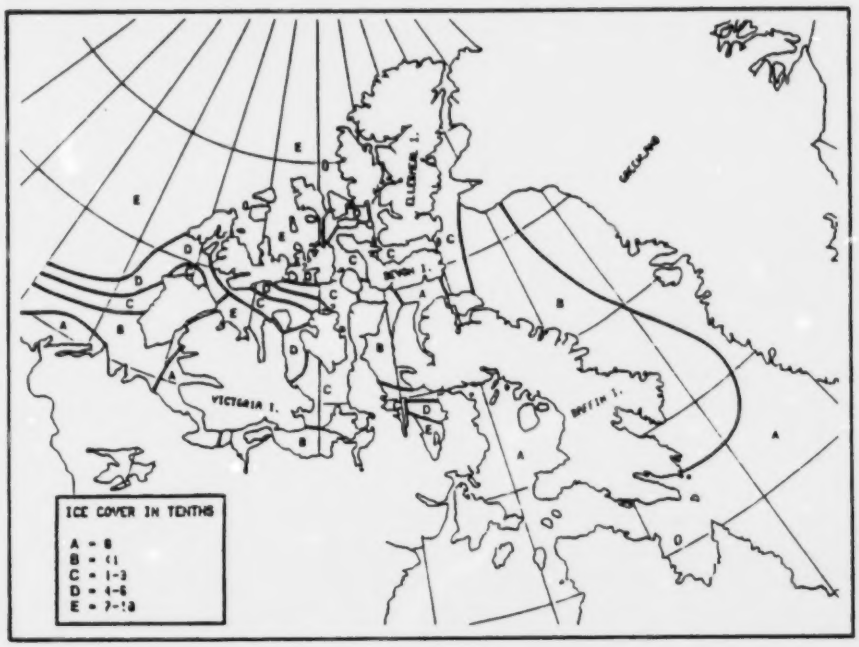
FIGURE 3.2.3

CONCENTRATION OF OLD ICE



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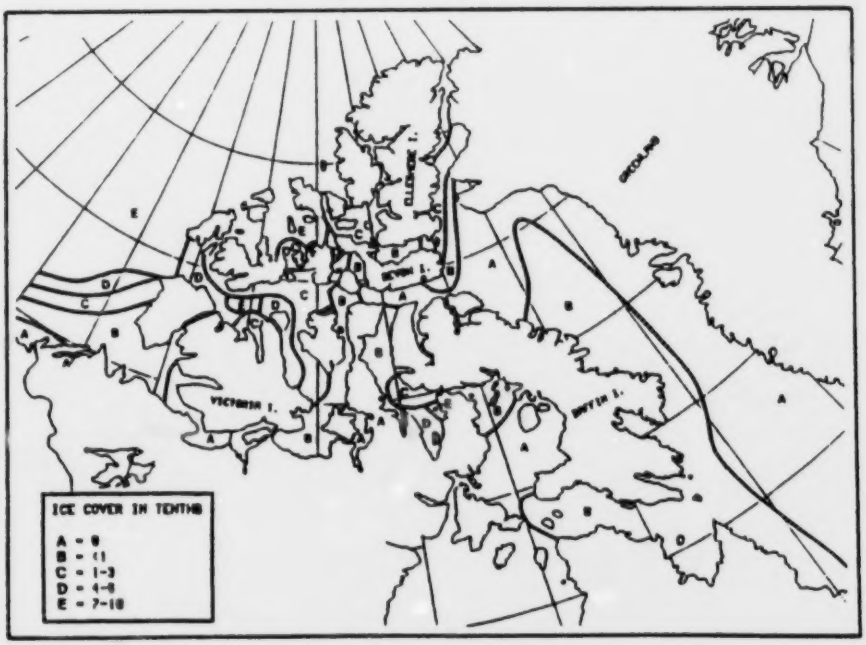


report reviews each area through which ships navigate and discusses the ice conditions from the viewpoint of the mariner.

3.2.4 Information Deficiencies

The review of ice conditions in the Arctic shows that there is a database available, the size and validity of which is quite varied. It is therefore to be expected that deficiencies will exist. These are described in the following notes.

a) Experience on board the M.V. ARCTIC has shown that the properties of both first year and old ice undergo a dramatic change during the warm spring and summer period. Investigations should be undertaken on the changing properties of ice during this period. Included with this investigation should be an analysis of where decayed ice is more likely and, conversely, less likely to be encountered.

   In addition, the properties of ice of all ages at different times of the year should be quantified. These measured properties should be collected in a manner such that they can be related directly to ship performance and structural requirements.

b) There are many facets of ice regimes which are not presently well understood. Future work should focus on:

   - an understanding of the factors which influence the consolidation and subsequent fracture of ice regimes, particularly in Lancaster Sound,

   - factors which influence the location, development and variability of ice pressure and rubbling,

   - ice motion and floe dynamics statistics, which should continue to be collected over the high Arctic.

c) Data collected on ice regimes should relate directly to ship's performance. This should be accomplished by undertaking demonstration projects and dedicated research voyages into ice regimes where data on ships performances do not presently exist.

d) The geographic distribution of glacial ice hazards in the eastern Canadian Arctic are not well understood. Research efforts should focus on quantifying the distribution of icebergs within Baffin Bay. In addition, the seasonal and annual variation of iceberg population should be quantified to investigate the effect, if any, of seasonal and annual climatic fluctuations of iceberg production and decay.

e) The movement of old ice out of Nares Strait into northern Baffin Bay poses a significant threat to navigation at the entrance to Lancaster Sound. Little is known about the pattern and variability of this old ice movement.

f) A reasonable amount of measured ice strength data are available for the Arctic regions, but in most cases the data from different times and locations cannot easily be compared or used to derive reliable design criteria because the results are highly dependent on test conditions. Much more effort is required to establish the conditions under which ice mechanical properties should be measured to develop design criteria.

g) The ice regimes of Baffin Bay, the high Arctic islands and the Beaufort Sea appear to operate independently. A good ice year in one location may occur at the same time as a bad ice year in another. The factors which influence the creation of a good or bad ice year should be investigated to ascertain if predicative models and long range forecasting is feasible.

h) Thousands of useful measurements of ice ridging taken by the AES laser profilometer, have not been analysed or published. Data from most resources including AES, U.S. Navy and other sources, provide misleading information because the ice regimes associated with the ridge data are not defined. The available data should be analysed to present comprehensive information on ridges in a way which is most useful to ship operators and designers.

3.3 Oceanography

The major bodies of water in the eastern Arctic include: Davis Strait; Baffin Bay; Jones Sound; Hudson Strait; Hudson Bay; and Foxe Basin. The major channel through the Archipelago is Parry Channel, with connecting channels to the south through: McClure Strait; Amundsen Gulf; M'Clintock Channel; Prince of Wales Strait and others. To the west, the Beaufort and Chukchi Seas form a contiguous basin with the Arctic Ocean and are connected with the Pacific via Bering Strait and Bering Sea. Each of the regions is unique in terms of bathymetry, tides, currents and wave climate conditions.

3.3.1 Bathymetry and Soundings

Bathymetric survey is difficult and expensive in the Arctic because of: the seasonal or year-round ice cover; darkness; cold temperatures; and infrequent ship traffic. Few of the Arctic waterways have been completely surveyed, and are charted from soundings along vessel tracks only. A few anchorages have been surveyed along closely spaced transits to modern standards, while parts of the Beaufort Sea, Parry Channel and Parry Islands areas have been surveyed to modern standards on grids ranging from a few hundred metres to a few kilometres.

3.3.2 Currents

Sea currents are an important factor in understanding the distribution and drift of sea ice and patterns of sea surface temperature in the Arctic. Several current systems are present and, while they are not strong enough to impose design constraints on a ship, they do indirectly influence the

ice and weather conditions. The major surface currents in the Arctic are illustrated in Figure 3.3.1.

3.3.3 Sea Conditions

The sea state in Arctic regions is less severe than in southern oceans because of limited fetch in the eastern and central Arctic and because the seas are ice covered during the fall and winter stormy seasons. Estimated signficant wave height for a 20 year return period in Baffin Bay is about 6 metres and this decreases westward into the Archipelago (Maxwell, 1980). Twenty year extreme significant wave estimates for the Beaufort Sea range from 6.3 metres in the deep water zone to 3.7 metres at 10 metre water depth. The wave climate becomes more severe in the Alaskan region because of a longer open water season. Twenty five year significant waves in the U.S. Beaufort sea are estimated at 13 metres and increase to 18.5 metres in the Bering Sea.

The sea surface temperatures can be considered close to freezing (-1.8 deg.C) through the winter when it is covered by ice. This temperature increases in summer after the ice cover dissipates, with seasonal maxima in August.

3.3.4 Ice Accretion

Ice accretion is not a severe problem in Arctic regions because of the seasonal climate conditions. In summer, air temperatures south of the permanent ice pack are normally above the limits for ice accretion, while in winter the ice cover prevents formation of freezing spray. Severe icing is normally expected in a narrow margin along the southern limits of the ice pack in winter.

3.3.5 Information Deficiencies

The review of Oceanographic conditions has highlighted several information deficiencies. These are described in the following notes.

a) Water depths are reasonably well known at a reconnaissance level for most of the Arctic waters, although shoals have not been well surveyed in most areas. The channels south and east of Victoria Island have many shoal areas and the reconnaissance surveys suggest that deep channels are not available. Additional surveys should be undertaken to establish the best route and sweep for uncharted shoals.

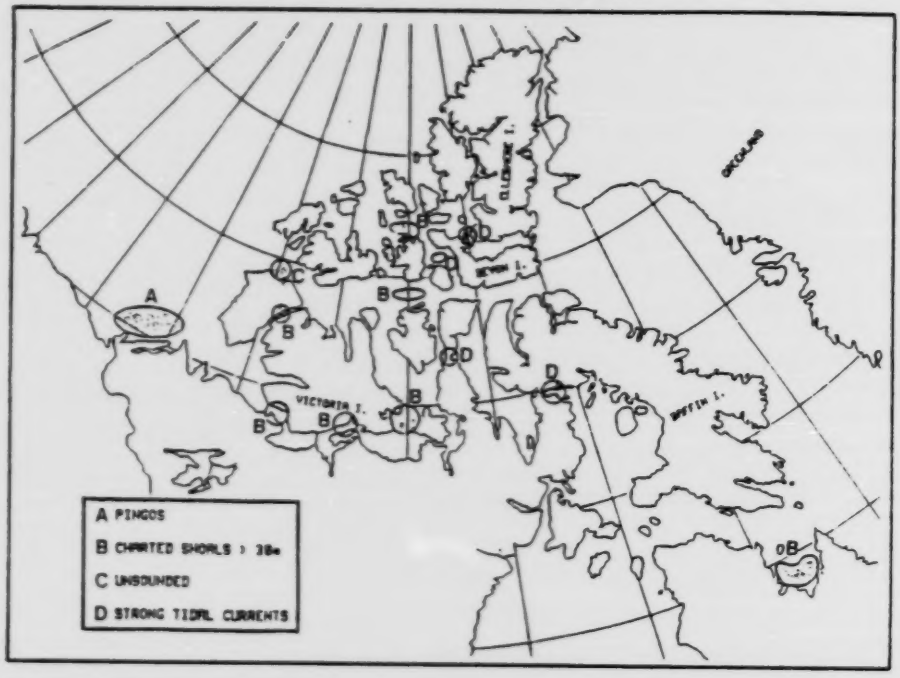
b) Current patterns and variability are poorly documented for the Arctic Archipelago. Consequently, the understanding of ice motion and, particularly, ice modeling will require a much more comprensive data set on currents. Areas of most concern are at the entrance to Lancaster Sound, Barrow Strait, and Viscount Melville Sound.

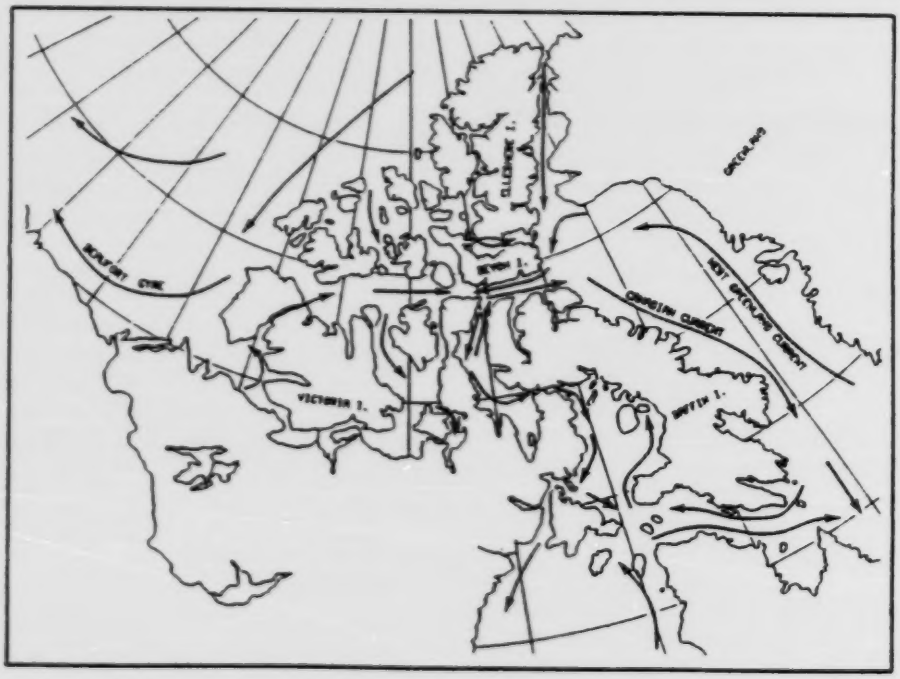
3.4 Meteorology

The climate of Arctic North America is influenced primarily by three pressure systems; an extensive high located over the north west part of the

FIGURE 3.3.1

OCEANOGRAPHIC HAZARDS AND SURFACE CURRENTS
OF THE CANADIAN ARCTIC





archipelago for much of the year, a low centered on the north east Atlantic and another low centered over the northern Pacific.

3.4.1 Air Temperature

As shown on Figure 3.4.1, air temperatures in the Arctic region show a distinct spatial and seasonal pattern. Spatially, the lowest temperatures occur in regions under continental influence, either from proximity to the Arctic mainland or to year-round ice cover. The highest winter temperatures occur in Baffin Bay and Davis Strait where the ice cover remains broken year-round. The lowest mean temperatures are found south of the Gulf of Bothnia, due to the continental effect. Summer temperatures follow a more meridional pattern, decreasing gradually toward the north.

3.4.2 Precipitation

Snow cover persists in the Arctic for much of the year but it is not an area of heavy snowfall. Precipitation is varied, being relatively high in eastern areas of cyclonic activity and low in the north west where the Arctic high predominates. Mean annual snow accumulation ranges from less than 50 cm in the southwestern Arctic to about 300 cm in the east. Rainfall accounts for roughly half the total precipitation amount in the southern Arctic but decreases toward the north and makes up only about 12 percent of the total at Alert (Maxwell, 1980). Much of the total rainfall occurs as drizzle during summer months.

3.4.3 Visibility

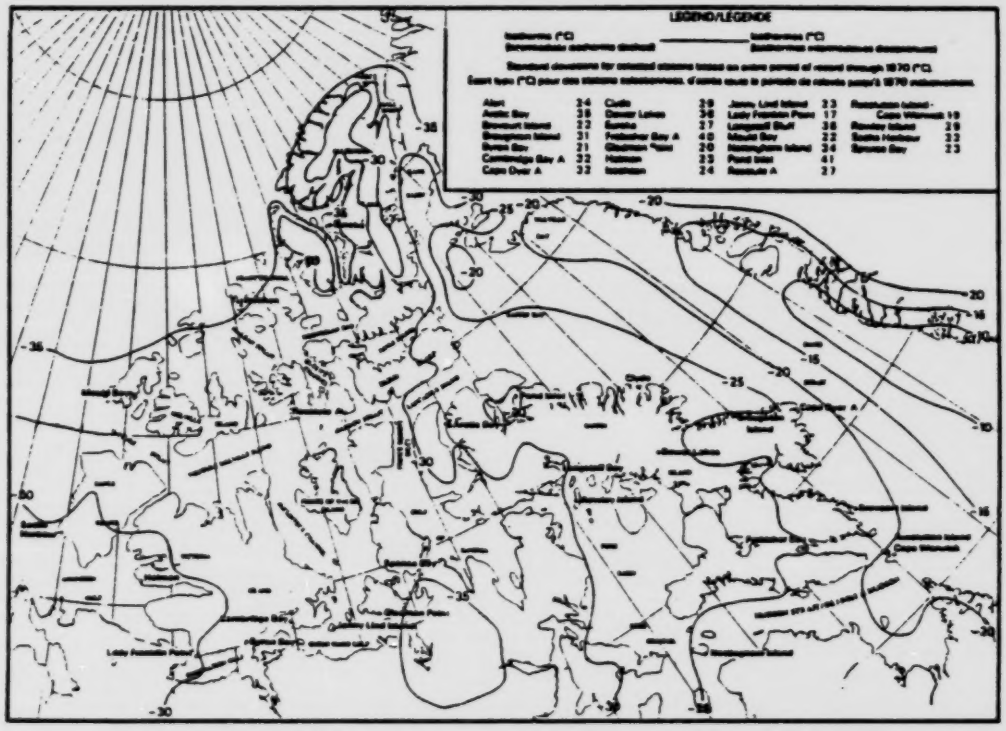
Advection fog is common during summer months and occurs when a warm air mass is cooled below the dew point when it passes over cold water or sea ice. It is widespread during the ice melt season and tends to be restricted along the ice edge as open water becomes prevalent. Steam fog occurs when cold air passes over open water. It is therefore localized over polynyas and along the southern ice edge and is prevalent only in winter. Blowing snow is a significant factor in winter visibility. Depending on grain size and compaction, snow begins to drift at wind speeds of 8 to 17 knots, and at 35 knots, visibility is limited to a few metres in almost all cases. In summer, drizzle or light rain occurs on average one day in three (CHS, 1982) but does not restrict visibility as severely as blowing snow in winter.

3.4.4 Wind

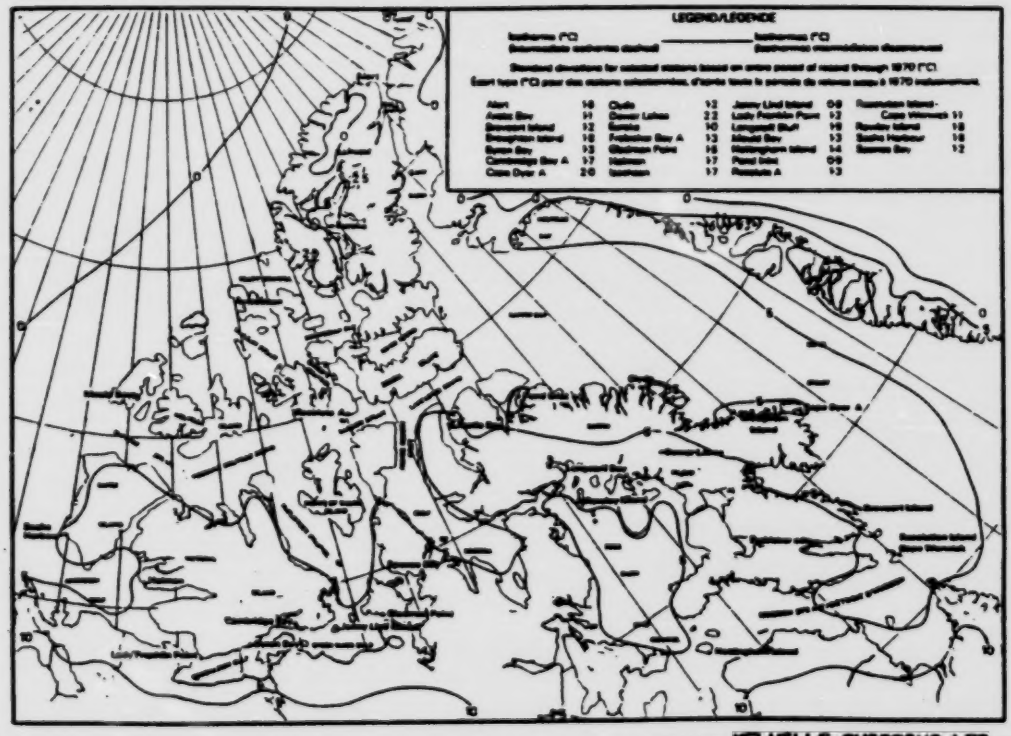
Wind plays an important role in the short term distribution and movement of ice in the Canadian Arctic. During the summer open water period, wind will greatly effect the movement of ice. During freeze-up, strong winds will create ice ridges. Wind has also been found to be the most important factor in the formation and maintenance of polynyas and flaw leads.

FIGURE 3.4.1

MEAN AIR TEMPERATURE



JANUARY
(DEG. C)



JULY
(DEG. C)

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Wind can also create ice pressure at critical locations. Such areas as the entrance to Admiralty and Navy Board Inlets and the south coast of Bylot Island, can experience extreme ice pressures when north east winds combine with the existing east flowing current to create high pressure conditions under eight to nine plus tenths ice conditions. Other areas where wind can create high ice pressure are at the entrance to Wellington Channel, southern McDougall Sound and Resolute Passage, the north west tip of Ile Vanier in Byam Martin Channel, and to a lesser extent, the north end of Erskine Inlet.

3.4.5 Information Deficiencies

The review of meteorological conditions has highlighted an information deficiency.

Wind and temperature influences on ice regimes are often difficult to quantify due to the lack of adequate data on these conditions over the Arctic. A programme of comprehensive weather data collection such as employing remote automatic systems should be undertaken. In addition, a wide body of weather data collected by shipboard observations should be continued and expanded.

4. SHIP OPERATIONS

4.1 Introduction

The operation of ships in Arctic waters can be said to have begun in earnest in the 17th Century with the northern whaling industry. However, little in the way of technological advancement was made until natural resources were discovered and exploitation was planned in the 1970's. Until this time, shipping in the Arctic was confined to the summer "open water" season for the resupply of isolated communities and government outposts. The Arctic Pilot Project, begun in the early 1970's, generated a surge of research into all aspects of commercial Arctic shipping. More recently, the extended season operation of the M.V. ARCTIC has provided valuable operational experience in Arctic waters and has demonstrated the direction and need for further research into commercial vessel operations.

4.2 Safety

The safe passage of ships has been essential to commerce since the first waterborne venture and it is natural that governments and international organizations have involved themselves deeply in the subject. Here in Canada, the Canada Shipping Act contains the bulk of safety regulations for ships.

4.2.1 Vessel Safety

Vessel safety, from the operations viewpoint, relates to the functions and potential problems related to a major fire, or to the need for damage repair or salvage in the event of a collision with another vessel or ice feature. The practical problems which will arise in these situations in a cold environment are quite different than if the environment was more temperate.

a) Firefighting

Research of the regulations of the IMO and various countries, who could be expected to have introduced legislation pertaining directly to fire protection and extinguishing equipment for use in sub-zero temperatures, has revealed that little attention has been focussed on the subject. Any references made to cold temperature conditions are vague and give little guidance beyond the phrase "shall be protected from freezing". The Canadian Fire Protection, Detection and Extinguishing Regulations are more specific than other countries in this respect but, even so, do not go far enough (Melville, 1985b).

The Marine Emergency Duties (MED) course syllabus, which forms part of the Canada Shipping Act, makes little reference to Arctic conditions as they affect firefighting, nor have any guidelines been identified.

b) Damage Repair and Salvage

The most recent investigations in this area have been completed by

Melville (1984). In the event of any damage which results in a fracture of the outer shell plating, the watertight integrity of the ship will be compromised. In this case, the rapid and correct performance of the crew will be paramount if the vessel is to be saved.

Few, if any, facilities in the Arctic could undertake major hull and/or machinery damage repairs to a vessel, such as the ARCTIC, engaged in winter operations. This does not necessarily mean that the ship is helpless, as much would depend on the ship's location and the extent and nature of the damage.

4.2.2 Personnel Safety

Personnel safety on-board ship is of paramount concern and governments have responded to the need to enforce personnel safety standards. The "Safe Working Practices Regulations" of the Canada Shipping Act apply to all Canadian ships whether in Arctic waters or not, and in the United Kingdom it is required that vessels carry on-board the Department of Trade's booklet "Code of Safe Working Practices for Merchant Seamen".

The regulations which are most closely concerned with ship abandonment are, for a Canadian ship trading internationally, the Canada Shipping Act Lifesaving Equipment Regulations and the I.M.O. Regulations chapter III, Lifesaving Appliances.

The various Lifesaving Equipment regulations currently in force have been designed primarily for ships trading in conditions having little in common with conditions in the Arctic. The regulations do not address the possibility of abandoning ship onto consolidated ice, thin ice or ice conjested waters, situations where the use of a lifeboat may be impossible or, at best, impractical.

4.2.3 Information Deficiencies

The deficiencies in relation to ship and personnel safety are confined to the requirements placed on the vessel, equipment and personnel in the event of a fire and/or abandonment situation.

a) The unique nature of the Arctic environment requires that special consideration be given to crew survival. The present regualtions provide only for ship abandonment in open water with no special consideration given to the Arctic. Research has been performed recently which identifies that shortfalls of the equipment presently carried on baord ship, and which recommends further development and testing of survival equipment and supplies. The recommended programme of research includes:

   - A programme of carefully designed and supervised field tests, of prototype and other available lifeboats and liferafts, to assess their suitability for Arctic use and to validate manufacturers claims.

- A programme of field tests should be pursued to assess the usefulness and requirements for more appropriate personnel survival equipment, inlcuding:

  . prototype and existing Arctic tents,
  . prototype and existing sleeping bags,
  . prototype and existing liferafts,
  . insulated clothing,
  . heatpaks, stoves and lanterns,
  . provision pack,
  . medical supplies

- A set of field tests, supported by investigations, should be pursued to assess the means of evacuation of personnel and survival equipment onto the ice, and methods of transportation of the equipment away from the ship.

b) Presently there is a lack of formal Arctic survival training. The existing courses on marine emergency duties do not cover the special circumstances which occur in the Arctic, leaving the ships' crew unprepared for the danges of abandoning ship and surviving while waiting for rescue. A training programme should be devised which will properly inform the ships' crews of survival techniques in the variety of conditions in which they will operate.

c) Firefighting systems on Arctic ships must be carefully designed to ensure efficient operation in extreme cold air temperatures. Some systems such as dry chemical powders are not affected by these extremes but the water, foam, and to some extent the gaseous systems, are adversely affected. The effectiveness of each of these systems has yet to be demonstrated during a major fire on board an Arctic ship. Demonstrations should be planned and carried out in extremely cold conditions on board Arctic ships. The results should be documented and used as guidance for operators and for a review of regulatory requirements.

4.3 Navigation

Navigation in the Arctic has always presented special problems to ships' officers. The combination of the normal navigation considerations with the difficulties imposed by ice hazard avoidance, the decreased usefulness of electronic navigation aids and the generally poor level of hydrographic coverage serve to make Arctic navigation more challenging.

4.3.1 Government Navigation Publications

a) Regulations

The various regulations within the Canada Shipping Act apply equally to all Canadian vessels whether in Arctic waters or not. Those directly concerning navigation of vessels in Arctic waters are:

- Charts and Publications Regulations Part I
- Navigating Appliances and Equipment Regulations
- The Arctic Waters Pollution Prevention Act

The following are also pertinent to Arctic Navigation;

- Arctic Canada Traffic System (NORDREG)
- Code of Navigation Practices and Procedures
- Ice Navigation in Canadian Waters
- The Mariners Handbook

The Collision Regulations are not reviewed as they make no specific reference to Arctic waters, although they must be strictly adhered to at all times and are implied throughout.

b) Hydrographic Charts

The Canadian Hydrographic Service (CHS) currently produces approximately 200 charts of the Canadian Arctic, their scales varying from 1:500 to 1:5,000,000, with most navigable areas covered at 1:500,000. Survey work is constantly being undertaken, however the area is so vast that many years of work are required before the Arctic is surveyed to the standards found on the eastern seaboard of Canada.

c) Tide and Current Tables

The Canadian Tide and Current Tables, Volume 4, cover the Canadian Arctic and Hudson Bay. Unfortunately the volume contains no current tables.

d) Sailing Directions

The Canadian Arctic is covered by three volumes of Sailing Directions. Volume I consists of general information pertinent to the whole Canadian Arctic. Volumes II and III give detailed descriptions and directions for the Eastern and Western Arctic respectively. The detail of information regarding coastlines, local ice conditions, shoals, etc. is poor compared to the Sailing Directions of, for example, Nova Scotia.

4.3.2 Navigation Aids

The Arctic is poorly served at the present time with navigational aids, and accurate position fixing is difficult. Considering radio fixing aids:

- LORAN C provides no Arctic coverage except in the eastern approaches to Lancaster Sound, where accuracy is suspect.

- DECCA provides no coverage north of 65°N latitude.

- OMEGA is available across the Arctic but extreme caution must be exercised in its use, particularly in the eastern Arctic where its signals are weak due to a loss of signal from Norway

caused by the shadow of Greenland. Accurate position fixes can, however, be obtained in the Beaufort Sea area.

- TRANSIT is a five satellite system through which accurate position fixing can be obtained from signals transmitted from a satellite orbiting 1,000 km above the earth. The time interval between fixes may lie between 20 and 40 minutes depending on the latitude of the ship.

- The GLOBAL POSITIONING SYSTEM (GPS) is a new satellite-based radio navigation system being developed by the United States Department of Defence. This system provides two coded signals, P code (military) and C/A code (commercial). Twenty-one satellites will be positioned (18 operational, 3 spare), orbiting above the earth at a height of 20,000 km and position fixing of the accuracy of about 50 meters (or less) will be obtainable 24 hours a day in any part of the world, since at least four of the satellites will be visible anywhere. By 1990 the complete 21 satellite system will be in place, subject to the availability of launch systems.

- RADIO BEACONS are located throughout the Canadian Arctic. The accuracy of such beacons in general is suspect and consequently little reliance can be placed on them.

By far the most important development in the field of "Navaids" is the GPS and, once fully operational, it will be of great value to Arctic shipping. The system is shown diagrammatically in Figure 4.3.1.

4.3.3 Shipboard Sensors

Traditionally, hazard detection in Arctic waters has been carried out visually. From the 1950's until very recently, although ships had some assistance from radar, it was still the accepted practice to stop and wait for good visibility. Now that ships are expected to operate continuously, and may eventually operate throughout the winter in darkness, this practice is no longer practical. Consequently various devices have been and are being developed.

a) Searchlights

Although searchlights have been in use for some time it is only recently that significant development has impacted on Arctic vessels.

In 1980 MPB Technologies Inc. began development of a 50 kW Vortex collimated, plasma arc, high intensity light source for marine use. Unfortunately, continued research into this device appears to have ceased. In 1982 commercially available 1000 Watt Xenon arc searchlights were evaluated on-board the ARCTIC (Robson, 1982). Although, these searchlights have greatly aided the detection of ice hazards, problems have been noted in the ability to distinguish between ice types, due to shadows and colour distortion. Currently a

2.5 kW Xenon arc is available on the market but no known ship evaluation has been made.

b) Radar

Although radar has been in general use on-board ships since the 1950's, it was not until the 1980's that serious research was started to develop an improved marine radar as an ice hazard detector. This came about as a result of various projects, notably the Arctic Pilot Project, Beaufort Sea drilling, Labrador Shelf drilling and coincident with the operation of the ARCTIC.

A typical marine radar (3 m antenna, 25 kw transmitter, low noise amplifier) mounted 30 m above sea-level can detect 'rough' floes at 6-7 nm. In a complex ice field all the ice is painted bright and may saturate the display. This makes it difficult to get adequate definition of shapes and ice types. Advanced radar aids (ARPAS) are radar systems designed to automatically track individual targets. These systems work extremely well for point targets like other ships and icebergs. They have not been designed to keep track of distributed targets like ice floes.

c) Sonar

Test results suggest that a commercially available calibrated sonar system can be used to obtain quantitative and qualitative data which relate echo level (amplitude) to iceberg size. Measurements of echo level from ice pieces less than 100 tonnes and very large icebergs greater than 10 million tonnes indicate a range in values of target strength from -15 db to 35 db per square metre.

d) Low Light Television

In the late 1950's, the term "low light level television" meant a system which could work well outdoors in natural lighting on a December afternoon. Today, low light TV systems are available which are rated to operate in starlight conditions (Benedict, 1979). Whether or not they give sufficient resolution and range for iceberg detection is not known.

e) SODAR

SODAR is an in-air acoustic detection technique which is still in the concept stage. It is thought that the device may help to detect icebergs and ice fragments at short range.

f) CODAR (HF)

CODAR (HF) is a high frequency over-the-horizon radar system. The application of this system is to detect and track icebergs in order that a greater level of accuracy may be obtained by drilling operations in determining whether or not the icebergs pose a collision threat.

FIGURE 4.3.1

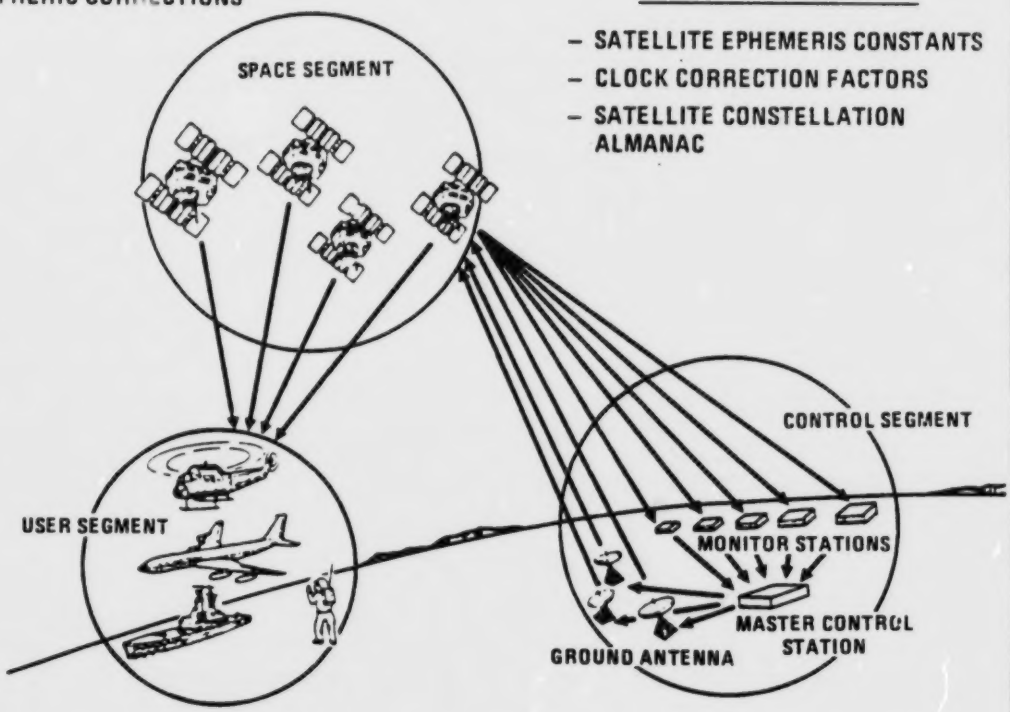
THE GLOBAL POSITIONING SYSTEM
(G.P.S.)

SATELLITE TO USER BROADCAST DATA

- C/A & P CODE RANGING SIGNALS
- SATELLITE EPHEMERIS
- CLOCK CORRECTION
- SATELLITE CONSTELLATION ALMANAC
- TWO-FREQUENCY DATA FOR ATMOSPHERIC CORRECTIONS

SATELLITE TO CONTROL UPLINK DATA

- SATELLITE EPHEMERIS CONSTANTS
- CLOCK CORRECTION FACTORS
- SATELLITE CONSTELLATION ALMANAC



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4.3.4 Remotely Sensed Information Sources

a) SLAR

Real aperture side looking airborne radars (SLARs) have traditionally been used to provide wide area photo-like imagery (50-100 km per side) shown on Figure 4.3.2, of Arctic sea ice. Ice classification is made on the basis of tone, texture and context of the data. The most severe drawback of SLAR for ice reconnaissance is that their azimuthal resolution varies as a function of range (typically from 50 m at near range to 500 m at far range). Furthermore, it becomes very difficult at far ranges to distinguish in-ice features essential for classification. Real aperture SLAR does provide a good overview for applications which don't require better resolution. For example, it is adequate for strategic route planning but is not suitable for tactical support (Canarctic, 1985).

b) SAR

The Synthetic Aperture Radar (SAR) is also used in a SLAR configuration. However, it provides a much improved resolution as shown on Figure 4.3.3 compared to the real aperture SLAR. The SAR achieves a very fine resolution in both range and azimuth by the use of signal processing. An encoded transmit pulse is used to generate a return pulse that can be compressed to any resolution. Improved azimuth resolution is achieved by compressing the entire doppler spectrum returned from a range cell as the radar passes over. By calculating the exact compression required at each range, azimuth resolution becomes independent of range.

Due to the relatively high resolution and the ability to downlink to ships having the required receiving capability, this system has been very successful operationally. The detail has been such that tactical routing of vessels by this means has not only saved time but has enabled those vessels to avoid all but the smaller (50 m) multi-year floes.

c) Satellite Imagery

Several satellites such as the NOAA, DMSP, and the NIMBUS series also carry thermal infrared (IR) sensors. The most important advantage of the IR sensors is their ability to operate in darkness and bad weather. Their limited resolution only permits the identification of gross ice boundaries and overall features within the ice pack. Ship-mounted IR systems for ice detection have received little attention.

4.3.5 Multiple Sensor Systems

Because no one sensor has been found to operate well under all conditions or for all ice types, attention has been directed towards the development of multiple sensor systems (Canarctic, 1985, 1986). In general terms these systems are attempting to integrate information from diverse sources and to present this information in a form easily interpreted by the navigator.

Airborne radar SAR imagery like that available from Intera's STAR-1 provides the right image characteristics and the right level of information

FIGURE 4.3.2

A.E.S. - NDZ SLAR
Image scale 1:250,000

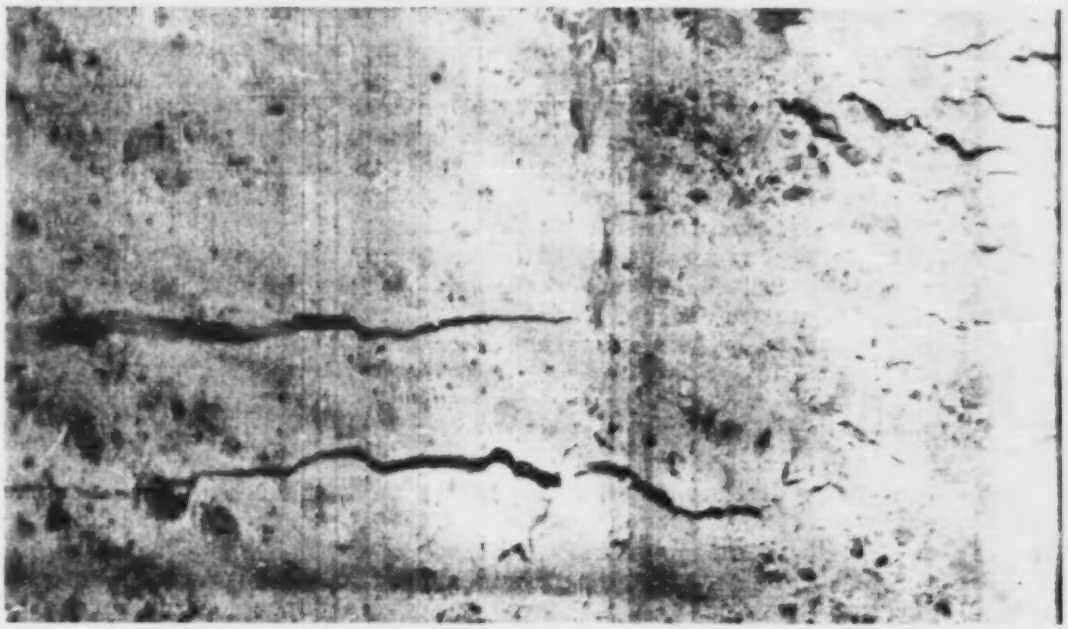
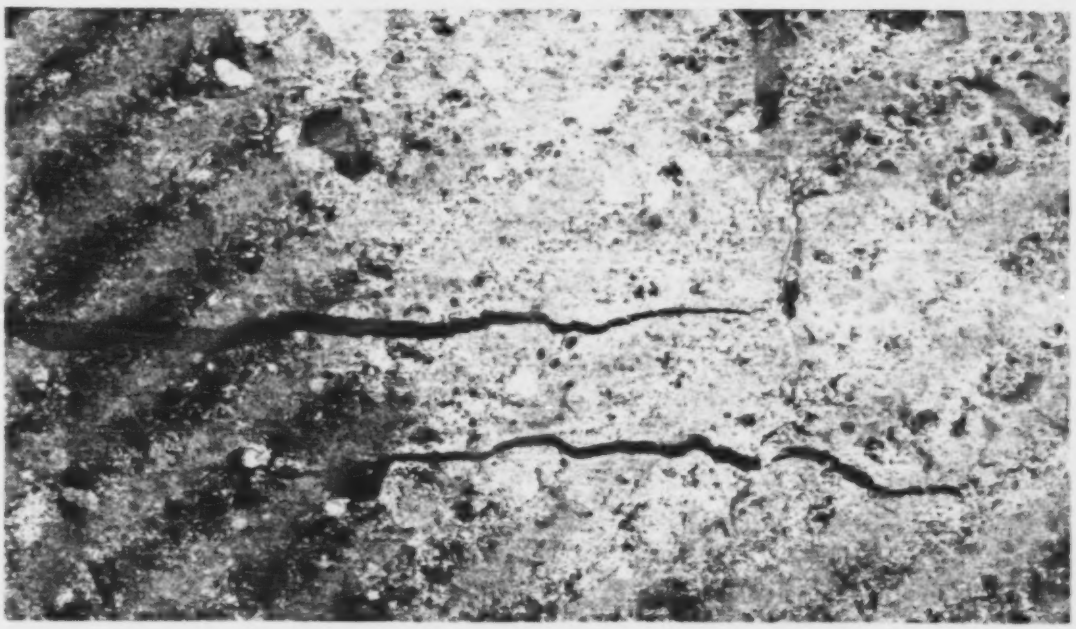


FIGURE 4.3.3

INTERA STAR - 1 SAR
Image scale 1:250,000



to be used as an ice navigation chart. By staging periodic airborne radar missions, geographically annotated airborne radar data can be telemetered to the bridge of a ship in real-time and used for ice navigation. The marine radar provides the means of tracking the position of the ship on the SAR imagery when ice conditions have changed. The geometric structure of SINSS is shown in Figure 4.3.5.

Canarctic Shipping Company Limited have been working towards the development of an integrated ice information system known as "SINSS" (Shipboard Ice Navigation Support System). This system, diagrammatically shown in Figure 4.3.4, has demonstrated that real-time ice information which is available from sources like airborne radars (SAR, SLAR), marine radars, and satellites (IR/visual), can be used for better route planning and tactical navigation by ships in transit through ice (Canarctic, 1986). With knowledge of the ice conditions in an operational region, a ship's Master can optimize his route and avoid areas where the risk of contact with ice or heavy ice is great. The resulting savings in ship operating costs, reduction in vessel damage claims, and improvement in delivery schedules have proven to be very substantial.

4.3.6 Precise Navigation Systems

This aspect of navigation, which is in use in various ports around the world, has only very recently been applied to Arctic harbours. The ship's position is obtained and automatically plotted on a VDU. The system can then be broken down into "positioning systems" and an "electronic chart system". Between the two is an integrated navigation system to combine positioning information and weigh it according to reliability. The "integrated navigation system" may either be part of the navigation system or the electronic chart system.

The three systems which seem to offer the best chance of availability and which are described in this section are:

- A microwave transponder precise inshore navigation system by Offshore Systems Ltd. of Vancouver.

- A passive radar reflector ranging system being researched by McMaster University.

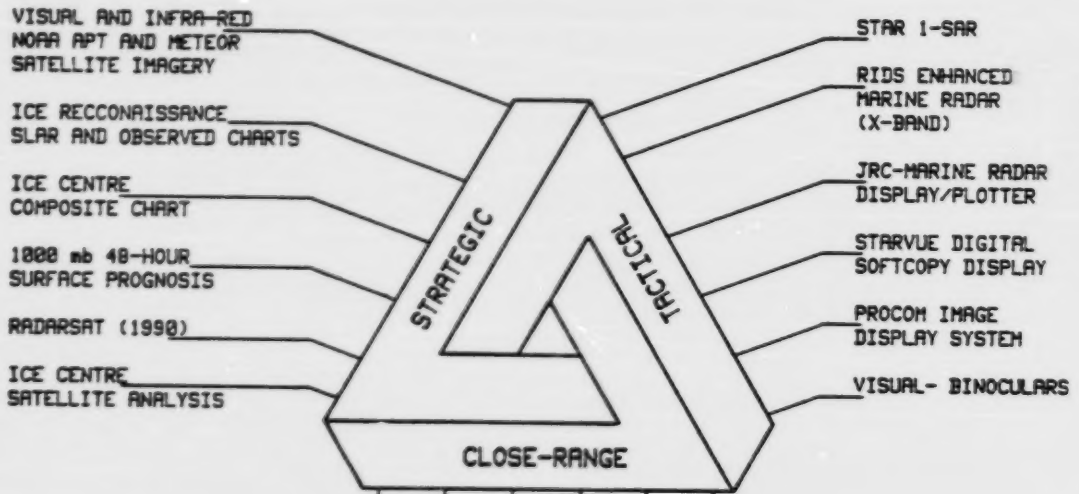
- Future satellite navigation systems.

4.3.7 Information Deficiencies

The deficiencies in relation to ship navigation relate mainly to lack of ability to detect ice and to understand the nature of the ice cover ahead of the ship. Successful navigation through areas of severe ice cover has been demonstrated with the aid of remotely sensing systems. However, this work is very much in the development stage and must be completed to secure the full benefits.

FIGURE 4.3.4

SHIPBOARD ICE NAVIGATION SUPPORT SYSTEM
(SINSS)



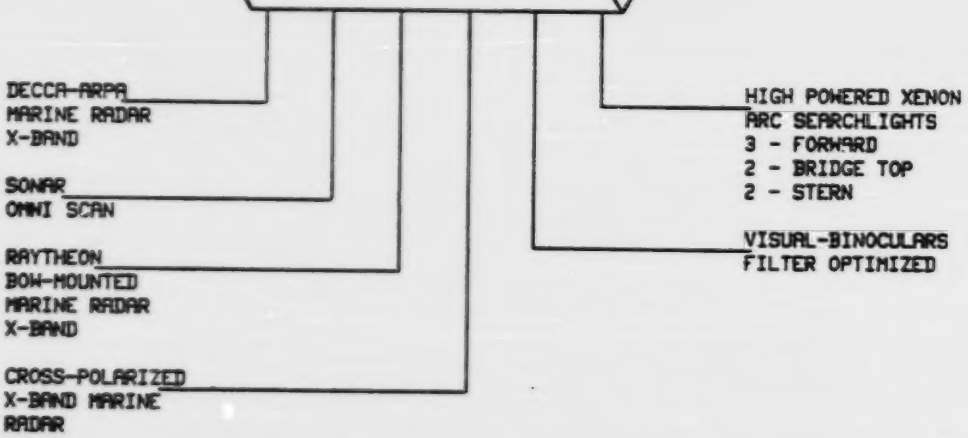


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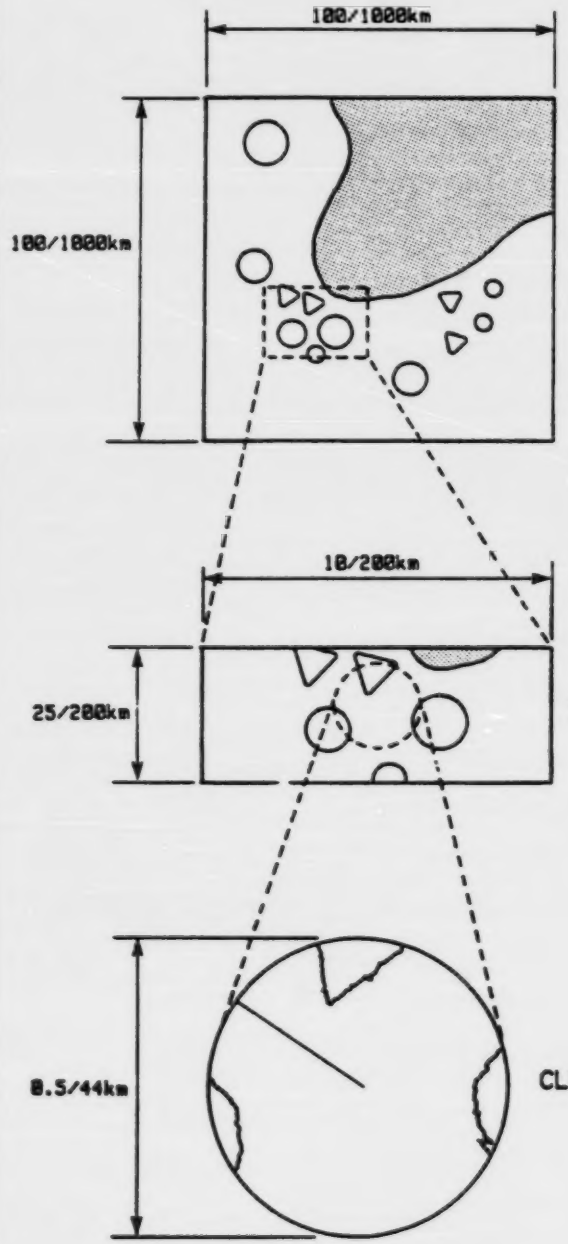
FIGURE 4.3.5

THE GEOMETRIC STRUCTURE OF A
SHIPBOARD ICE NAVIGATION SUPPORT SYSTEM (SINSS)



SATELLITE

- NOAA
- LANDSAT
- METEOR

AIRBORNE RADAR

- X-BAND SLAR
- X-BAND SAR

MARINE RADAR

- S-BAND 10cm
- X-BAND 3cm (BRIDGE)
- X-BAND 3cm (BOW)

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a) SINSS has proven to be a most valuable tool, however, the system requires operational assessment and fine tuning under winter conditions. The areas requiring improvement are:

- utility of the METEOR APT Satellite images.
- utility of ice forecasting services.
- improved weather data acquisition.
- improved soft copy downlink systems.
- improved high speed computer manipulated and enhanced marine radar displays.

b) It is unlikely that electronic sensors will ever fully replace the visual detection of hazardous ice, in the close tactical sense. Therefore, it is most important that continued research be carried out to improve searchlights or other light sources. The present difficulty in distinguishing between ice types when using searchlights should be examined and solutions sought.

c) In order to improve marine radar detection techniques a data collection programme is necessary to obtain radar data for small ice targets in sea clutter. In addition, investigations should be continued into data processing techniques which show promise for increasing signal-to-noise ratio and signal to clutter rations.

d) Field programmes are necessary in order to support and extend present knowledge regarding fundamental properties of acoustic propagations in Arctic waters. Important here are investigations into the frequency dependence of target strength and in the signal to noise aspects of various transducer configurations and installations. Propagation characteristics under ice also demands attention. From a theoretical point of view some research into the statistical nature of sonar echoes and their relationship with radar echoes from the same target is also thought to be important.

Of more immediate concern to the design of a suitable sonar for ice hazard detection are the hardware problems associated with the deployment of a transducer assembly within the bow area of the vessel. In this respect the positioning and 'look direction' of a sonar transducer would have to be identified and the beam pattern and scanning rates defined. Further investigation into ship and ice generated noise is also desireable.

e) A programme should be pursued of continued Arctic class Nav-Aids research, development and implementations having due regard to the eventual impact of GPS on the need for traditional Nav-Aids. Emphasis should be on the Coronation Gulf route through the North West Passage.

4.4 Communications

Ships all over the world depend upon an effective maritime mobile communications service for the safe and efficient management of their voyages. This is never more applicable than in the Arctic because of its hostile climate, uncharted waters and vast expanses in which there are few ships that can help in case of emergency.

4.4.1 Coast Guard Radio Stations

To perform the tasks of the maritime mobile communications service, the Telecommunications and Electronics Branch of the Canadian Coast Guard operates and maintains a national network at 52 coast radio stations strategically located to provide optimum coverage according to prevailing ship traffic densities. Of these fifty-two radio stations, seventeen are located in the Arctic.

These stations regularly broadcast, as specified in "Radio Aids at Marine Navigation", the following essential navigational information to shipping by means of radiotelegraphy, ratiotelephony and facsimile;

- weather forecasts for specified marine areas,
- actual ice cover conditions and forecast conditions,
- navigational warning messages called "NOTSHIPS" which cover a wide range of conditions from a misplaced positions of a buoy to the unavailability of a Coast Guard radio station.

For the shipping company, fast and reliable communications to and from its ships is of the utmost importance for the economic management of its fleet. The "public correspondence service" which the Coast Guard operates makes possible this essential communications link between ships and their shore-located operating base. This service allows for the sending and receiving of radiotelegrams and where applicable, direct person-to-person contact by radiotelephone.

Until recently, Transport Canada was, for all practical purposes, the only supplier of ship-shore communications in Canada. Today however, Teleglobe Canada has entered the Maritime Mobile Satellite Service through its participation in INMARSAT, and there is the strong possibility that the commercial carriers will participate directly in the Maritime Mobile Service through future VHF/UHF automatic radiotelephone systems.

4.4.2 Forecasts and Ice Advisories

The Arctic Canada Traffic System (NORDREG) Centre at Frobisher Bay opens in early July and is manned until the end of October or as long as ships are at sea in the area. This office provides current information on ice conditions, advice on the best routes to follow, icebreaker support, where available and considered necessary, and the organization of convoys if required. The daily production of ice forecasts is the responsibility of Ice Forecasting Central in Ottawa.

The Atmospheric Environment Service (A.E.S.) ice reconnaissance aircraft are equipped to transmit fascimile maps and side looking airborne radar (SLAR) imagery directly to vessels having the receiving equipment. This information is generally real-time or close to real-time.

4.4.3 Radio Communications

Maritime mobile frequency assignments fall into three major categories, commonly referred to as Medium Frequency, MF (300 KHZ-3 MHZ),

High Frequency, HF (3 MHZ-30 MHZ) and Very High Frequency, VHF (30 MHZ-300 MHZ). Well known examples of typical maritime frequencies in the MF and VHF frequency bands that have special international status as general calling and distress frequencies are:

500 KHZ/Morse Code (MF)
2182 KHZ/Voice, Radiotelephone (MF)
156.8 MHZ/Voice, Radiotelephone (VHF)

These frequencies may be used by the entire maritime community for the purpose of establishing an initial contact with a coast radio station or another ship or to broadcast an emergency. Therefore, Coast Guard facilities transmitting or receiving on these safety frequencies must have exceptionally high reliabilities.

4.4.4 Satellite Communications

a) INMARSAT

The INMARSAT satellite system interfaces directly to the end user's telephone on the mobile side of the satellite. It extends the terrestrial telecommunications networks to the oceans of the world.

The maritime satellite system has three major components: the satellite capacity leased by the organization, the coast Earth stations and the ship Earth station. As can be seen on Figure 4.4.1, INMARSAT does not cover very much of the Canadian Arctic. In practice the coverage area is slightly better than shown. Experience has demonstrated, for example, that contact is possible in the entrance to Lancaster Sound.

b) M.S.A.T.

MSAT is a multi-beam satellite system designed to provide Canada-wide voice and data services to mobile users and planned to be launched in the late 1980's. The system is intended to complement local terrestrial mobile radio networks by taking advantage of the large coverage area afforded by a satellite system (coverage up to roughly 75^{o}N is planned).

c) Telesat Satellite Network

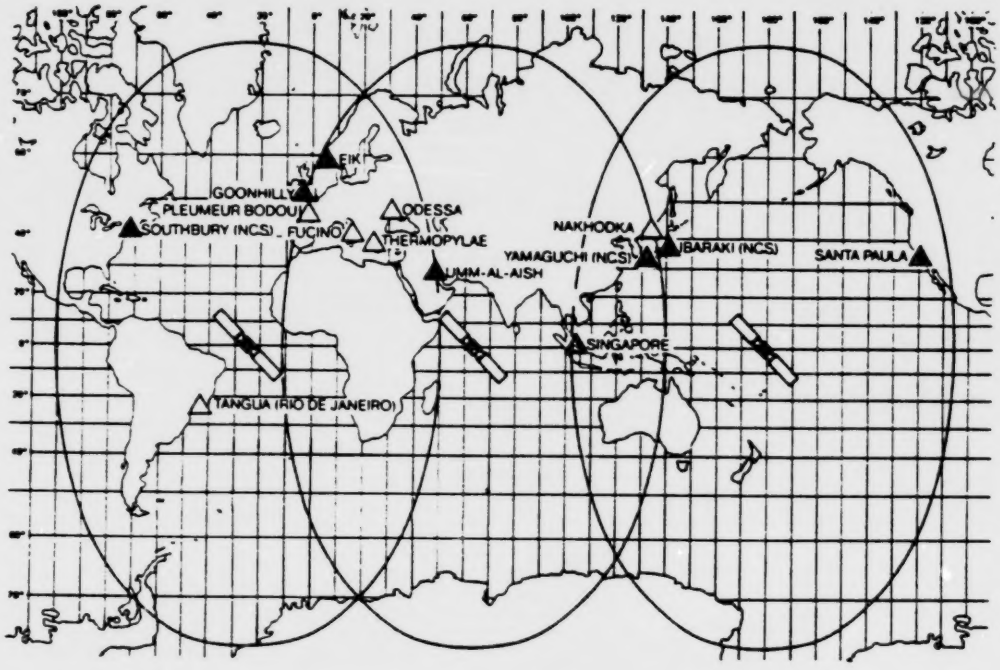
Telesat Canada operates a commercial satellite communications system throughout Canada. The system includes a space segment, consisting of active 6/4 GHZ and 14/12 GHZ satellites in geostationary orbits, and over one hundred earth stations of several different types. Currently, both the remaining Anik A Satellites (two of the three launched have already been retired) and the Anik B satellite are nearing the end of their useful lives. The Anik C series of satellites offer a coverage area that is biased towards southern Canada. The Anik D series operate at 6/4 GHZ and provide all-Canada coverage.

4.4.5 Future Global Maritime Distress and Safety System

This system will be a milestone for Inmarsat, because one of its major

FIGURE 4.4.1

EXTENT OF THE INMARSAT SYSTEM



▲IN OPERATION △PLANNED

The Inmarsat satellites provide near global coverage (to about the 75° latitudes) so that a ship can communicate via satellite virtually anywhere. As of 1 December 1983, there were eight coast Earth stations in operation with several more scheduled to joint them in 1984. Three of these are Network Coordination Stations (N.C.S.), which assign telephone channels on demand to requesting ship Earth stations.

objectives is to provide improved facilities for distress calls and communications to improve safety of life at sea. The immediacy and reliability of Inmarsat communications have already led some countries to include the ship Earth station as an alternative main transmitter for mandatory carriage on ships covered by I.M.O. Safety of Life at Sea (SOLAS) Convention. Many more countries are expected to follow suit as I.M.O. prepares its new SOLAS requirements.

One objective of the future system is to enable any properly equipped ship to achieve automatic distress alerting and be located with minimum delay. As well, it is expected that most rescue centres will be equipped with satellite communications so that they can have direct access to the Inmarsat system and will, as a consequence, be able to contact vessels, similarly equipped, in seconds in the event of a distress or emergency at sea.

4.4.6 Safety Radio, Devices

Emergency Position Indicating Radio Beacons (EPIRB's) are now required to be carried by certain classes of ships (SOLAS 1983). These devices, when activated, transmit a signal on a number of frequencies (121.5 MHZ, 243.0 MHZ, 2182 KHZ) which can be picked up by aircraft, shore stations and more recently by satellites operating under the Sarsat-Cospas system. The devices are intended to "float free" from a vessel and are self-activating.

4.4.7 Information Deficiencies

The deficiencies in relation to communications relate to the improvement of ship to shore contact, and to the transmission of data to and from the ship.

a) As an interim solution to communications problems in the Arctic, a project aimed at enabling a ship to access the Anik D system should be carried out. The major problem will be the development of a suitable antenna and stabilization platform.

b) Reliability testing in the field of an HF modem and channel eveluation system is required.

5. SHIP DESIGN

5.1 Introduction

Arctic ship technology can be reviewed as several major areas of interest: structure; hull design and performance; propulsion; and general outfit and auxiliary systems.

5.2 Structure

Arctic ship structural design is evolving and improving as a result of intense activity over the past number of years. Improvements have derived from both technical advancements as well as from experience on the new ships.

5.2.1 Load Criteria

The best current data for Arctic ships comes from three ships; the M.V. ARCTIC, M.V. KIGORIAK and the USCGC POLAR SEA. Modern instrumentation systems can accurately measure ice pressures over many adjacent panels, based on frame response, and can derive total load from hull girder response. Some recent Baltic Sea data is also relevant to ice loads in level ice, and contributes to our understanding of ice failure. The following data is of most use:

Polar Sea - Thousands of events measured in first year and multi year ice on areas from .15 m^2 to 9 m^2, a Peak force of 5 MN, and a Peak Pressure of 12 MPa (.15 m^2).

Kigoriak - Hundreds of events measured in multi year ice and ridges, on areas from .2 m^2 to 5 m^2, a Peak force of 23 MN, and a Peak Pressure of 18 MPa (.2 m^2).

Figure 5.2.1 shows peak values of pressure versus area of measurement for the important data sets.

Another way of deriving ice pressures is to examine the experience of ships such as the KIGORIAK, POLAR SEA, TERRY FOX, KALVIK, and M.V. ARCTIC. This base of experience (some with damage and some without) can be used to infer appropriate design ice pressures. The recent regulatory proposal by CANMAR is an example of this. CANMAR proceeded by assuming the nature of the ice load (i.e., aspect ratio, pressure/area effect, amount of bridging) and then using the Kigoriak scantlings, derived the magnitude of the ice pressure. While this approach may result in incorrect extrapolation, it does at least ensure that design will concur with experience.

5.2.2 Materials

The selection of steel grades suitable for use in ships' structures which are exposed to very low temperatures has been under extensive study recently by the classification societies, regulatory authorities and others. Draft regulations and proposals have been made and some

classification societies have already introduced a materials section in their rules for Arctic class vessels (Lloyds Register of Shipping; American Bureau of Shipping; Bureau Veritas).

At present there is a lack of consensus in regard to appropriate steel grades for Arctic vessels. The general opinion of Arctic ship operators is that the steels used in the present generation of ships are mostly adequate. This opinion is based on the generally satisfactory performance of Arctic vessels, although, it should be noted, the sum total of experience in the Arctic is much smaller than shipping in warmer waters. The research community tend towards the view that some of the more advanced steels, with very high toughness at low temperature, are appropriate for critical portions of ship structures. In interpreting the latest research, the regulators have been making their requirements increasingly more stringent.

The corrosion of welded joints (exposed to seawater) in Arctic ships has become prevalent in recent years. Accelerated corrosion of the weld metal and of the heat affected zone of welds has been noted in Canada, Finland and Russia. In Canada, Japan and Finland work is presently in progress to study weld line corrosion in ships under Arctic conditions.

5.2.3 Local Structure

The plating generally makes the largest contribution to the structural weight of most ships, and together with the frames and stringers forms stiffened panels. While lightness can sometimes be attained by increased framing and reduced plate thickness, this is usually accompanied by increased fabrication cost.

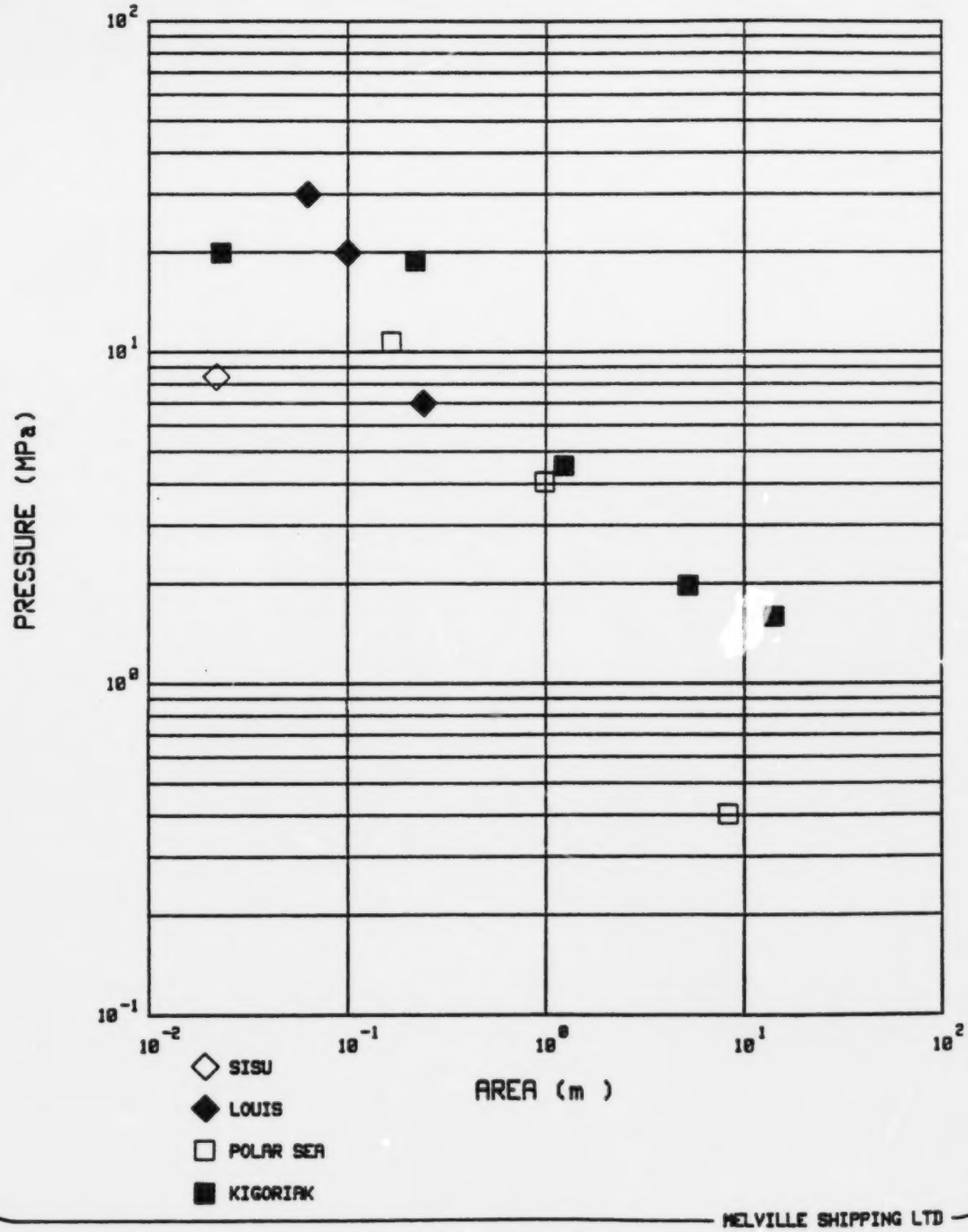
The most elementary approach to plate design is based on small deflection theory. This theory yields accurate estimates of deflection and bending stress for displacements much less than the plate thickness. However, small deflection theory is not adequate for predicting the ultimate capacity of the plate primarily because membrane action is ignored in the theory. This has lead to the development of large deflection theory in which the increase in load-carrying capacity due to membrane action is accounted for. Recent analyses and experiments have investigated plate behaviour beyond the elastic limit including both bending and membrane action.

Design of plate elements and frames are often governed by a limiting permanent set, except when instability, for example, tripping of stiffeners, is a consideration. The establishment of appropriate limiting values of permanent set is difficult and incorporates some degree of subjectivity.

The ultimate strength of thin plating can be many times larger than the yield strength, due to the membrane behaviour at large deflections. While both deflections and rupture strength are of concern in ships, it is necessary to define the acceptable limits of both. A number of excellent papers have been written (Jones, 1976; Ratzlaff, 1986) which examine the behaviour of flat plates under uniform lateral loading.

FIGURE 5.2.1

SHIPBOARD MEASUREMENTS OF PRESSURE VERSUS AREA



Depending on the type of behaviour which is acceptable, different equations will specify thickness of plate. These are shown in Table 5.2.1.

Framing supports the shell plate, and individual frames act like beams, resisting the loads on the shell by both bending and shear. Most serious structural damage due to ice pressure has involved failure in the frames. This type of failure often manifests itself as tripping of frames and shear yield in deep frames.

The CASPPR Hull Structure Requirements are currently under extensive review and are soon to be updated. Several recent proposals have been made by Classification Societies and others, notably; American Bureau of Shipping, Lloyd's Register, Det Norske Veritas, CANMAR, ARCTEC CANADA, and the U.S. Ship Structures Committee.

The Soviet Union and the Finnish-Swedish Board of Navigation have each recently issued revised regulations. However, only the upcoming CASPPR rules will reflect all of the recently gained full scale experimental data and experience.

Table 5.2.2 presents a comparison of various approaches to structural requirements. It is clear that a very wide range of approaches can be employed. In most cases the design pressure is (artificially) low, while elastic or 3-hinge plastic design is employed for both plating and framing. None of the methods explicitly employ probabilistic design.

5.2.4 Hull Girder Structure

The hull girder response to ice impact is outside the scope of traditional methods. The primary reasons for this are the very limited experience of ship-ice interaction, and the transient nature of the problem. In the ramming mode the dynamic response characteristics of the hull girder become important. This mode bears some resemblance to the more familiar 'slamming' problem.

For the purposes of hull girder design the major effort has been directed towards the development of empirical expressions relating to the maximum ship/ice impact forces. The "design" case of concern in the Canadian Arctic is the ramming of large old ice floes and ice islands.

Five ships which have yielded some full scale data on total force and hull girder stress due to ramming heavy ice. These are:

KIGORIAK:	218 measured rams in July and October 1983.	Highest force of 25 MN @ 4.5 m/s, in grounded multi-year ice.
ROBERT LEMEUR:	116 measured rams in June 1983.	Highest force of 16 MN @ 3.2 m/s in a grounded first ridge.

TABLE 5.2.1

COMPARISON OF VARIOUS PLATE DESIGN FORMULAE

	CONDITION	EQUATION	PERMANENT SET (w)	REFERENCE & DATE	COMMENTS
1.	1st Yield	$t = .707\ s\ (P/f)^{.5}$	$w = 0$	Timoshenko (1959)	Elastic beam theory
2.	1st Yield	$t = .667\ s\ (P/f)^{.5}$	$w = 0$	Timoshenko (1959)	Elastic beam theory, Poissons effect included
3.	1 Hinge	$t = .544\ s\ (P/f)^{.5}$	$w = .7\ s^2f/(tE)$	Hughes (1983)	Plastic edge hinge, Poissons effect included
4.	1 Hinge	$t = .32\ s\ P^{.75}E^{.25}/f$	$w = .005\ s$	Clarkson (1956)	w equivanent to welding deformations
5.	2 Hinge	$t = .397\ s\ (P.f)^{.5}$	$w = t$	Hughes (1983)	Aspect ratio = .25. Edges free to pull in.
6.	3 Hinge	$t = .5\ s\ (P/f)^{.5}$	unspecified	Johansson (1967)	Beam theory
7.	3 Hinge + Membrane	$t = .353\ s\ (P/f)^{.5}$	$w = t$	Jones (1976)	Beam theory
8.	Membrane	$t = 1.25\ s\ P/f$	$w = .1\ s$	Jones (1976)	For aspect ratios of 2:1 and greater
9.	Membrane	$t = 1.01\ s\ P/f$	$w = .1\ s$	Ratzleff/ Kennendy (1986)	Poissons ratio and edge angle included.

TABLE 5.2.2

COMPARISON OF REGULATORY REQUIREMENTS

	RULE or PROPOSAL			
ITEM	CASPPR (1971)	FINNSWED (1984)	LLOYD'S Prop. (1983)	ABS (1983)
1. No. of Classes	9 Arctic + 4 Baltic	4 Baltic	4 Arctic + 4 Baltic	5 Arctic + 3 Baltic
2. Highest Class	10	1A SUPER	AC3	A5
3. Design Ice Pressure Procedure (MPa)	from Table II	P=cd*ct*ca*po depends on D,N,spacings	from Table	P=Po*Fo depends on D,N,angles
Example Ship	P=10.34	P=3.69	P=3.92	P=11.78
4. Shell Plate Formula	t=.667*s*√(P/f)	t=.578*s*√(P/f)+2	t=.5*s*c*√(P/f)+9	t=.6*s*√(P/f)+6
Example Ship	t=45.21	t=25.4	t=52.8	t=49.4
5. Frame Design Method	Section Modulus	Section Modulus	Section Modulus	Section Modulus
Example Ship	Z=862 cm3	Z=215 cm3	Z=523 cm3	z=418 cm3

	RULE or PROPOSAL			
ITEM	RUSSIAN (1982)	ACL Prop. (1986)	CANMAR Prop. (1986)	SSC-309 (1981)
1. No. of Classes	4 Icebreaking +5 Navigation	4 Arctic +4 Baltic	4 Arctic +4 Baltic	–
2. Highest Class	LL1	U	U	–
3. Design Ice Pressure Procedure (MPa)	P=6.88*D^1/6 *(1+.003*N)	P=(4.6*D^1/12* kp^.023-.7)/√s	P=(7.6+.0124* FMAX)/(2*s)	P=[p(T,S)*ft*fr]
Example Ship	P=12.58	P=29.6	P=10.88	P=7.45
4. Shell Plate Formula	t=.6*s*√(p/f)+6	t=1.25*s*Pp/f	t=.5*s*√(BPP/f)+2	t=.353*s*√(P/f)
Example Ship	t=50.8	t=41mm	t=36.8mm	t=20.3mm
5. Frame Design Method	Section Modulus	Shear Area	Shear Area	Section Modulus
Example Ship	Z=679 cm3	A=140 cm2	A=125 cm2	Z=517 cm3
Example Ship: Takes on Highest Class		D=25kT	L=160m	N=22MW
		s=400mm	b=1000mm	Bow Region
	B=24	alpha=40deg	beta=60deg	f=360 MPa

Note: Framing Design is complex in all methods. Rigorous comparissons depend on many details.

POLAR SEA:	40 measured rams in October 1985.	Highest force of 25 MN @ 4.5 m/s in multiyear ice.
M.V. ARCTIC:	143 measured rams in June 1984.	Highest force of 23 MN @ 2 m/s in multiyear ice.
MANHATTAN:	2 measured rams in October 1969.	Highest force of 72 MN @ 2.5 m/s against a (non-infinite) ice island (force is estimated to be only 50-70% of value if ice island had been "infinite").

Figure 5.2.2 plots measured values of force as a percentage of displacement against displacement along with extrapolated values to 16 kts (linear extrapolation). These points are compared with the two equations.

$$F = 5.2\ D^{.9} \quad (\text{if } P = D^{2/3})$$

and

$$F = 1.6\ V\ D^{2/3}$$

where :

F = Force (MN)
V = Velocity (m/s)
D = Displacement (kT)
P = Power (MW)

These two formulae are typical of current proposals for maximum ship/ice impact force and are only meant to be used in conjunction with the highest ice class.

There is a consensus in Canada today that only the highest ice class should have regulations governing hull girder modulus. For lower ice classes, the designer is to choose the modulus based on engineering judgement, and to ensure ship safety, install a hull girder stress monitoring system, with bridge display. The M.V. ARCTIC has such a system today.

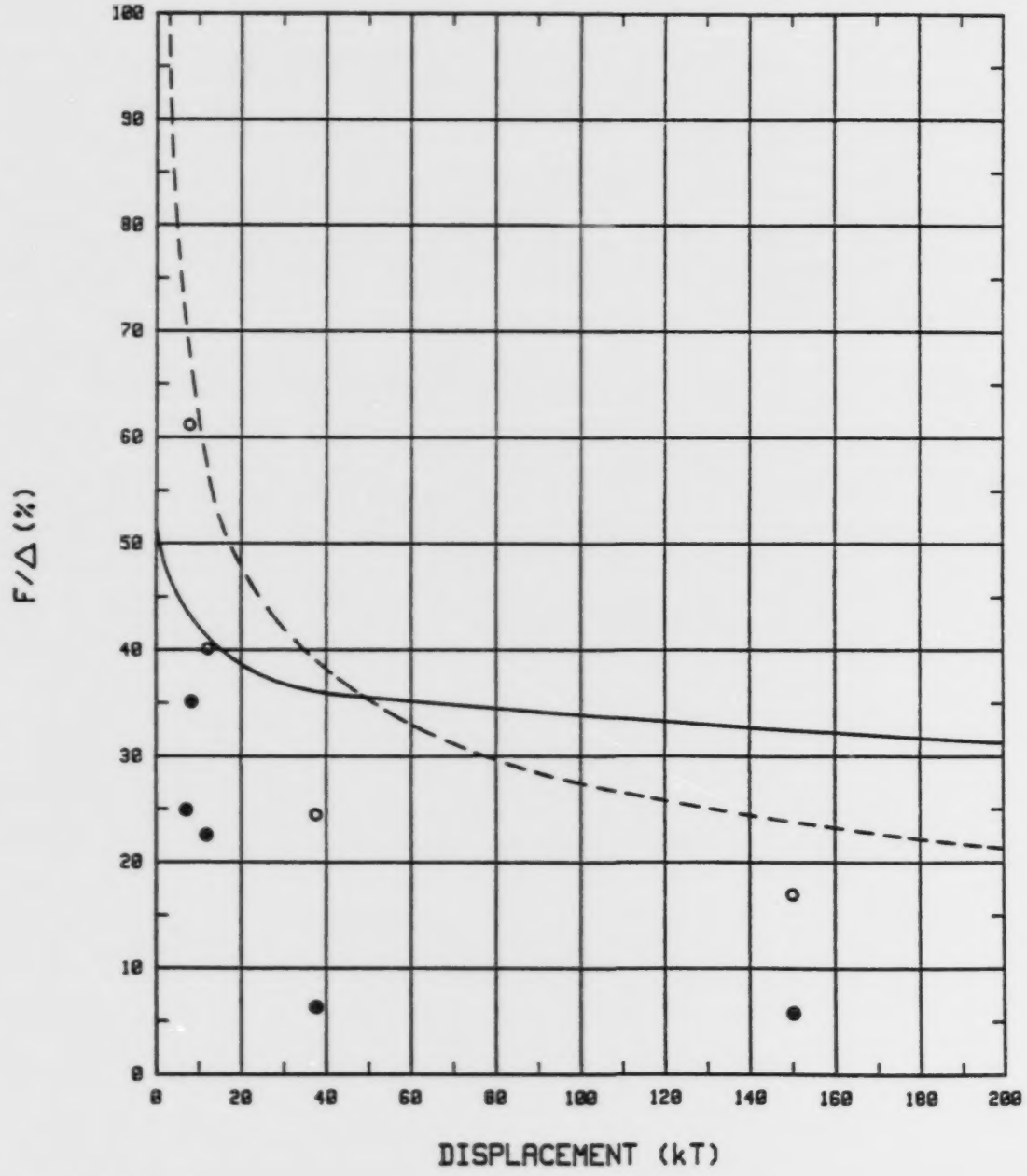
While it is clear from the evidence that a large ship with open water hull section modulus (i.e. the M.V. ARCTIC) would not be able to withstand a full speed impact with 'infinite' ice, it is felt that 'due caution' of mariners will ensure that ramming speeds are kept low until the master ascertains if the ice is a threat to the ship.

5.2.5 Information Deficiencies

The deficiencies in relation to ships' structures relate to the loads to which the structure must be designed, and the materials which should be used. The lack of design load data is the most important deficiency, and should be the highest priority. This is reflected in the present high level of research activity in this area.

FIGURE 5.2.2

FORCE (%) VERSUS DISPLACEMENT FOR
HEAD-ON SHIP/ICE IMPACT



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a) To update plate design methodology it is necessary to establish realistic loading for multi-year ice and to account for the actual strength mechanisms. The designer or regulator must decide on the design condition (i.e., percent of permanent set) and the design life. If the design condition for the plating is to be a permanent set of more than three percent of the frame spacing, then membrane action must be the design behaviour.

   The best currently available plate strength formula is by Ratzlaff and Kennedy. This approach, among others, should be examined as a way of improving design methods. In addition, the effect of aspect ratio, and load reduction due to plastic behaviour is not well understood, especially in thick plates.

b) Framing may also be designed plastically, except that shear is likely to be the critical stress. Some analysis of buckling and tripping has been performed, but has not yet become standardized in the design spiral. Investigations of plastic or buckling response require sophisticated finite element programs such as ANSYS, ABACUS, ADINA or NASTRAN.

   A concerted effort should be made to understand the complete behaviour of framing under ice loads and to standardise the design methods.

c) The hull girder loads which may be encountered by existing or future ships are still uncertain. The information base which is available covers only a few Arctic ships and of those only two, ARCTIC and MANHATTAN, provide data which applies to high L/D ships. This problem may be addressed in a number of ways:

   i) A long term programme of full scale stress measurements on existing Arctic ships will create a data base of information, which will guide the designer, operator and regulator.

   ii) The numberical modeling of ship/ice interaction during ramming requires an accurate model of ice behaviour. The existing numerical models do not deal effectively with this requirement. The behaviour of ice under load must be investigated to improve the predictive capability of these models. Full scale measurement of ice response to ramming may be the only reliable way to obtain the data.

   iii) The physical modeling of ship/ice interaction during ramming requires the ice to behave similarly at model scale and full scale. The ability to simulate the full scale response of the ice must be developed.

   iv) For numerical models of ship/ice interaction during ramming, the ship's 'added mass' is of great importance. Work is already underway on this problem.

d) Investigation is required on fracture toughness criteria that are economic to apply. The criteria should incorporate the effects of temperature, stress level, thickness and loading rate.

e) Experimental work is required in which the air and sea temperature is correlated with temperatures in the structure. A two-pronged approach could be used in which results from full scale experimental programmes are used to validate and/or calibrate numerical approaches.

f) The sensitivity of fracture behaviour of steel to strain rate has been noted. Although some data has been gathered, further data is required to establish the spectrum of strain rates experienced by Arctic vessels.

g) The problem of weld corrosion is the subject of current research and this effort should continue. Past research has indicated that the chemical composition can be adjusted to yield favourable properties, but often at the cost of reduced toughness.

5.3 Hull Design and Performance

This section deals with the many aspects of hull design and performance. Performance is defined as the ability of a ship to operate in a variety of ice conditions, and the following discussion reviews the background and present understanding of:

- hull form design,
- performance enhancing systems, and
- performance prediction techniques.

5.3.1 Hull Form

The hull shape of icebreaking ships is driven by a primary consideration; the lowest power required to make progress in ice. Secondary considerations include; power in open water, manoeuvring, and protection of the propeller(s). Fundamental to the selection of a hull form are the following considerations:

- performance in ice of all types
- performance in calm open water
- performance in heavy weather in open water
- manoeuvring capability
- choice of overall dimensions
- ease and cost of construction, and
- ease of repair
- ship type (cargo, icebreaker, etc.)

While traditionally shaped icebreakers are still being built, there has recently been constructed a variety of ships with non-traditional shapes. In many cases these designs have been predicated by one particular consideration, such as 'construction cost', 'icebreaking' or 'manoeuvring'. Notwithstanding this, the understanding of hull shape has improved greatly in recent years.

The bow shape of an icebreaker is usually considered to have the four basic design features shown on Figure 5.3.1. Flare angles contribute to

the ice 'breaking' and submergence efficiency, waterline angles contribute to the ice 'clearing' efficiency, the stem angle contributes to the 'breaking' and 'submergence' efficiency and is associated with the flare and waterline angles, and forward block coefficient, which relates to the 'clearing' efficiency and is associated with the flare and waterline angles.

The progression over the last fifteen years has been to; increase frame flare, reduce waterline angles, reduce the stem angle, and reduce the forward block coefficient, all designed to produce a more efficient icebreaking bow. Many programmes of model testing have been performed to verify these relationships, some are well reported in the literature (Edwards, 1976; Narita, 1981; Noble, 1981) and others are proprietary.

However, the selection of bow shape is greatly effected by the vessels mission profile, and this is reflected in the shapes which have been adopted over the years.

a) Straight Stem With Parallel Buttocks
b) Concave Stem (White Bow)
c) High Flare Angles (Melville Bow)
d) Spoon Bow With Reamers
e) Semi Spoon Bow With Chines
f) Flat Family
g) Thyssen-Waas Bow

These bow shapes can be referred to as 'unconventional' or 'non-traditional' in that they are a distinct departure from the smooth hull shapes. It would appear from Figure 5.3.2 that the the best of the traditional shapes has performed as well in level ice as the best of the non-traditional.

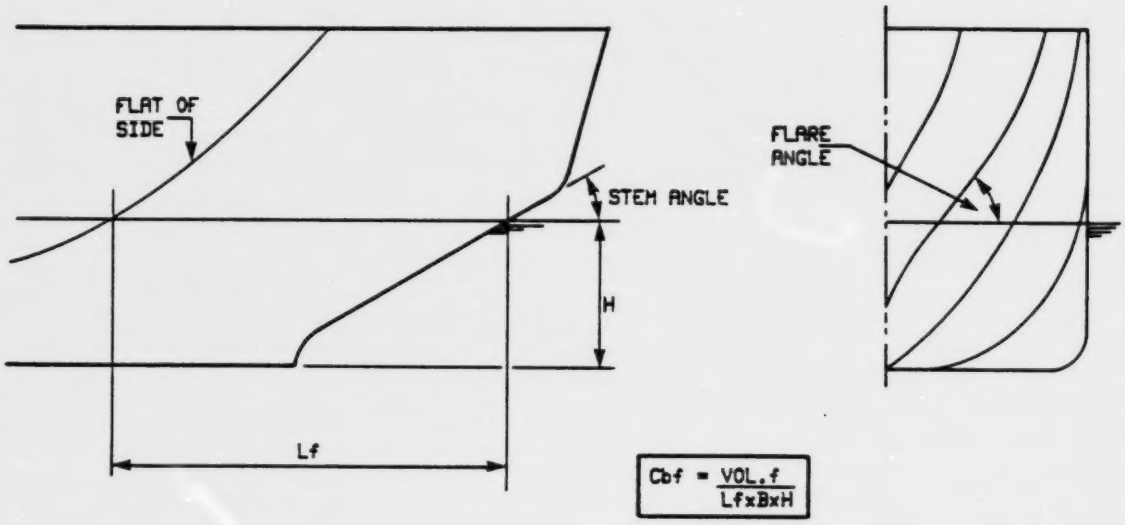
The selection of midbody shape has in the past, almost without exception, dealt only with three parameters; flare angle, parallel midbody, and longitudinal taper. This is reflected in the shapes which have been adopted over the years. The midbody shape of icebreaking cargo ships is governed largly by the vessels length, but also by the need to minimise construction costs. While some vessels do have midbody flare most have vertical sides. By contrast, icebreaker operators are more concerned with the ships ability to maneouvre than with construction cost or with resistance. For this reason it is likely that pure icebreakers will retain the concept of limited parallel midbody, while improving the icebreaking efficiency by appropriate design of the shoulder shape.

All icebreakers are designed to move astern in ice. Some may only operate in that mode in a broken channel or in broken ice, others such as those which perform a support role must break ice while moving astern. Depending on the mission profile, these ships are designed either with an ice breaking/defecting stern shape and/or with an ice horn(s) which prevents oblique loads on the rudder(s) when in the midships position.

The selection of a stern shape has in the past been governed primarily by the number of stern propellers. More recently, the objective of protecting the propeller from ice interaction has generated a number of new

FIGURE 5.3.1

BOW FORM FEATURES



$$Cbf = \frac{VOL.f}{Lf \times B \times H}$$

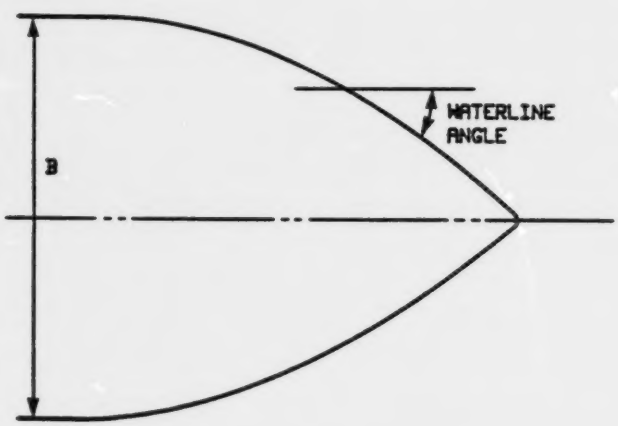


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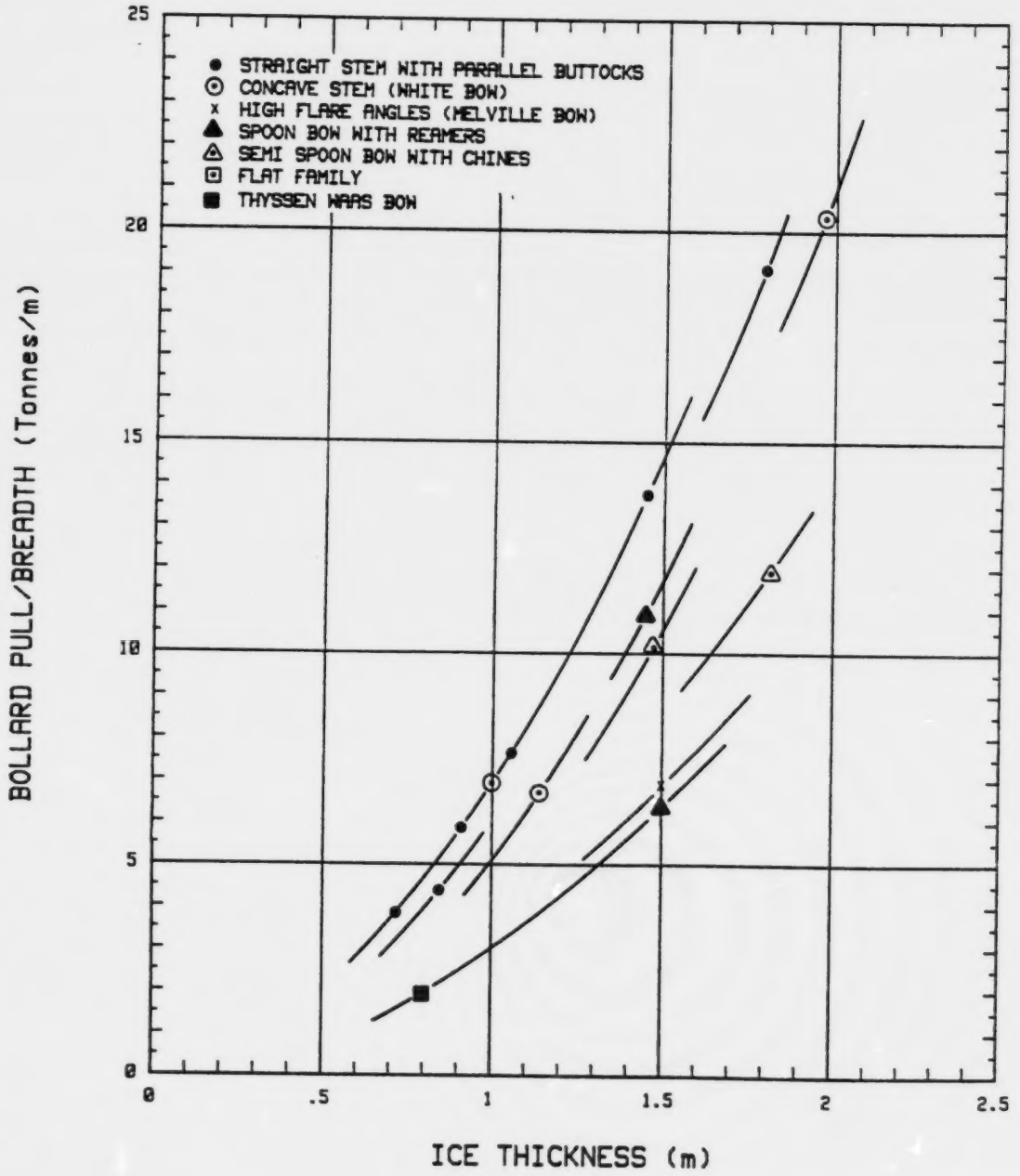
FIGURE 5.3.2

ICEBREAKING PERFORMANCE
OF SEVERAL HULL SHAPES



Bollard pull is measured or calculated
Data is adjusted for a 2 knot ship speed

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model scale. The ice characteristics that are considered important in model scale are: flexural strength; crushing strength; shear strength; elastic modulus; fracture toughness; and friction.

The most important characteristics are ice thickness and flexural strength. Thickness can be reproduced to within about 1.0% of the thickness and the flexural strength to within about 5-10% of the strength.

Crushing strength is generally too low at model scale when the appropriate flexural strength is scaled correctly. As a result, care must be taken when model testing a bow that tends to crush ice excessively since its performance will be overestimated. The shear strength of model ice has not been investigated in detail, however, from the little work that has been done it is considered to be representative of full scale.

The elasticity of the model ice is usually represented as a ratio of the elastic modulus and flexural strength (E/J). In full scale this ratio is believed to be about 3,000 - 4,000, at model scale it ranges from about 900 - 1,200, but may drop as low as 200.

The friction coefficient has been recognised as a major problem in model ice testing for many years. Conventional Froude scaling, which assumes Coulomb type friction between the ice and hull, requires the (non dimensional) friction coefficient to be identical between prototype and scaled model. Recent work on full scale vessels instrumented to measure friction (Hoffman, 1986; Enkvist, 1986) and sample testing of model and natural ice (Forland, 1985) indicate that the friction phenomenon is not Coulomb but dependent on normal force, relative motion, surface configuration (material sliding on ice or ice sliding on material) and roughness.

b) Analytical and Semi-empirical Models

Early attempts to formulate the ice resistance problem date back to Runeberg (1888), who analyzed the forces and friction at the stem of an icebreaker. This attempt was followed by slow progress until Kashteljan (1968) proposed the first rational breakdown of the ice resistance into components based on functional mechanisms of icebreaking. These mechanisms include breaking, submersion (or gravity) and speed related (inertial) effects.

Since Kashteljan's work, several studies have followed, and many models have been proposed for the prediction of level ice resistance and the evaluation of concepts in the initial stages of ship design. Published reviews of such models have been performed earlier by Edwards (1978) and Nawwar (1979). These reviews have also been updated in 1983.

Table 5.3.2 provides a summary of analytical and semi-empirical level ice resistance models. This table provides an overview of the type of data used in developing the models, and the number of terms used in each; with the exception of computer coded models which are usually too complex to be described by a single equation. The table also lists the country of origin where the model has been developed.

stern shape concepts. From experience gained in the Beaufort Sea it is apparent that, despite the innovative stern designs, there is still substantial propeller/ice interaction, leading again to the conclusion that the design must be chosen after considering all aspects of the selection process.

5.3.2 Performance Enhancing Systems

Until the mid 1970's icebreakers used heeling systems and/or bow propellers to reduce the drag forces acting on the ship during ramming operations. The motion of the ship when the heeling system is operating, or the turbulence created by the bow propellers, helped to lubricate the hull/ice interface and hence reduce the friction forces. These systems are still options, although bow propellers are no longer installed on icebreakers. Generally, these two systems have been replaced by the use of 'low friction coatings' or a combination of these coatings and one of several hull lubrication systems.

The systems which are presently installed are:

- the 'Air Bubbler System', installed on many vessels including the LUNNI class, ARCTIC, and the S.A.15s

- the 'Air Bubbler/Water Injection System', installed on the POLARSTERN, and

- the 'Water wash System', installed on the CANMAR KIGORIAK and ROBERT LEMEUR

Very little information is available on the performance of ships when fitted with these means of reducing hull/ice friction.

5.3.3 Performance Prediction Techniques

The major problem associated with the prediction of performance for an ice transitting ship is the variability of the environment in which it may operate. In the case of the Canadian Arctic this may include any combination of level ice, rubbled and rafted ice, pressured ice or pack ice. As a result of this variability the performance prediction of icebreakers is usually confined to specific ice regimes, characterised with 'average' or 'typical' values. The most common ice regime used for this purpose is level ice.

It is common for the icebreaking ship designer to use more than one procedure to assess the performance of a ship in ice, and as a result he should be familiar with their assumptions, limitations and reliability.

a) Model Scale Tests

The ice model basins which are presently operating are shown on Table 5.3.1. The objective of model tests is to evaluate the full scale performance of an icebreaker by observations and measurements taken at

Many different parameters can be included in the ice resistance equation. Several parameters appear consistently in most equations. These are: ice strength in flexure; ice thickness; ice density; water density; gravity; ship beam and ship velocity and the dependent variable of resistance. Sophisticated models also try to determine the influence of hull shape. This is found by terms containing combinations of such variables as entrance angle, stem angle, bow angle, water plane area, and flare angles.

5.3.5 Information Deficiencies

The deficiencies in relation to hull design and performance are in the two areas of optimising the shape of icebreaking ships and in predicting accurately the performance in a range of ice conditions. The benefits which can result from research in this area are substantial and can greatly influence the economic viability of future Arctic shipping systems.

a) There is a need for verification of the fundamental assumptions usually made in theoretical level ice prediction models so that the proper breakdown of resistance components can be made by source.

b) A level ice performance prediction capability should be developed based on the known full scale performance of icebreaking ships. The international database is substantial but disorganised and presently unsuitable for use in this manner. The known performance must be related to hull form and size and to the predicted performance based on model tests. Model tests may be used to complete the family of performance data which can be used for interpolation or extrapolation to make accurate predictions for future ships.

c) The optimum hull form for Arctic ships depends on the ships mission profile and to some extent the cost of construction. The search for an optimum shape should continue, learning from the experience of the last ten years. A programme of hull form optimisation should be encouraged, covering the needs (sometimes different) of icebreakers and icebreaking cargo ships.

d) The present inability of model ice to correctly simulate the breaking patterns and strength of the ice leads to uncertainty when using model tests to predict the performance of ships. Although much research has been completed in this area, and progress is being made, the problems are far from solved. Some of the most recent work has highlighted the inability of model basin tests to accurately simulate full scale.

e) An improved procedure is required for monitoring model ice strength parameters in the same time frame and at the same speed as the ship model is being run. This procedure would relate, more accurately, the ice strength to the model shape, and make adjustments for the effect of shape on the model test results.

f) The present understanding is poor of the effects and importance of friction on the results of model tests. The important aspects of this problem relate to both full scale and model scale friction. Present

TABLE 5.3.1

ICE BASINS OF THE WORLD

YEAR	COUNTRY	CITY	FACILITY OPERATOR	TYPE OF DOPANT	BASIN DIMENSIONS LENGTH (m)	WIDTH (m)	DEPTH (m)
1955	U.S.S.R.	Leningrad	Arctic and Antarctic Research Inst.	Salt (3%)	13.50	1.90	1.70
1969	Finland	Helsinki	Wartsila Shipyard	Salt (2%)	39.00	4.80	1.20
1970	Canada	Calgary	Esso Resources	Salt (Var)	54.90	30.50	3.00
1971	W. Germany	Hamburg	H.S.V.A.	Carb (1%)	37.00	6.00	1.50
1974	U.S.A.	Columbia	Arctec Incorporated	Salt (.4%)*	30.50	3.70	1.50
1977	Canada	Kanata	Arctec Canada Ltd.	Carb (.5%)*	30.50	4.90	1.50
1979	U.S.A.	Hanover	C.R.R.E.L.	Carbamide	36.60	9.20	2.50
1981	Canada	Ottawa	N.R.C. Hydrau. Lab	Carbamide	19.00	7.00	1.20
1981	Japan	Tokyo	Japan Ship Res. Inst.	Carb/Salt	35.00	6.00	1.80
1981	Canada	Calgary	Arctec Canada Ltd.	Modice	30.5	7.3	1.4
1982	Japan	Nippon Kokan	Carbamide	Carbamide	20.00	6.00	1.50
1983	Finland	Helsinki	Wartsila Shipyard	Salt (2%)	77.30	6.50	2.30
1984	W. Germany	Hamburg	H.S.V.A.	Carb (1%)	78.00	10.00	2.50
1985	Canada	St. John	N.R.C. (IMD)	EG/AD/S	90.00	12.00	3.00

* Tanks now also using modice.

techniques attempt to either simulate correctly the friction coefficient, or run the tests at a nominal value and correct the results for the type of ship being tested i.e., new and old. A programme of research should be initiated to determine at full scale the magnitude of the friction forces, and how, at model scale, to simulate those forces.

g) Recent work on the hydrodynamics of model ships in ice has shown that the thrust deduction factor may not be properly simulated. These recent results have indicated descrepancies of up to 400 percent of the value which is obtained during clear water model tests. This difference has a large impact on the prediction of performance at full scale and therefore on the power which may be installed as a result of those tests.

h) An analysis of existing data on the level ice ramming capability of icebreaking ships will be a starting point from which a better understanding may be gained of overall ramming performance. The available data should be assembled and, along with details of the ships, used to begin the development of a ship ramming performance prediction model.

i) Ship performance in ridges has received very little attention in the past. Ridges are much more complicated ice features than level ice, and, despite the many years of work on the latter, there is still no accurate model for performance prediction. The areas which require further investigation include:

- ship/ridge interaction mechanisms,
- pressure ridges, failure modes,
- development of simplified algorithms for prediction of ship performance,
- development of methods for modelling pressure ridges at model scale.

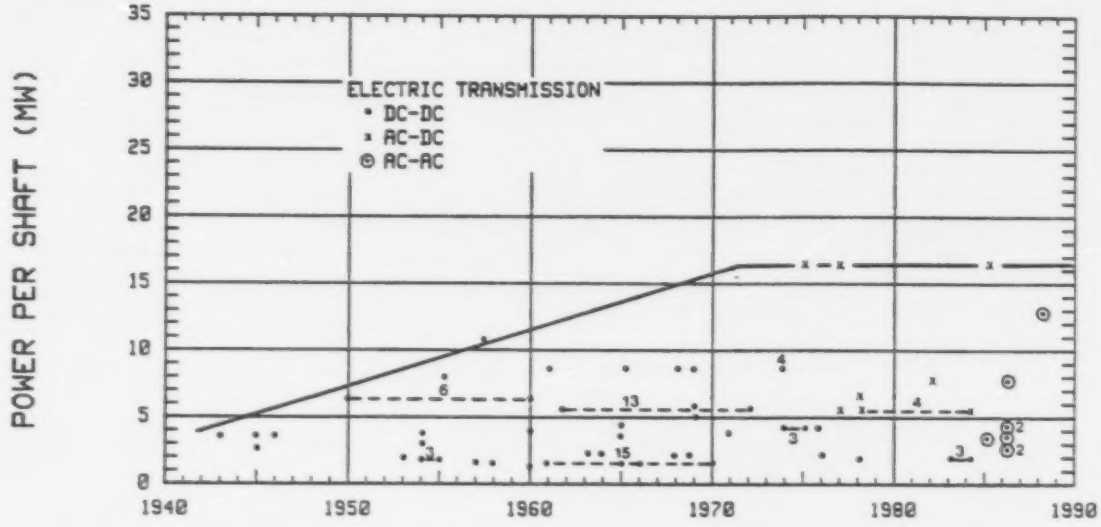
j) Experience of model resistance and 'English style' self propulsion tests, during which the model is restrained in the fore and aft direction, has demonstrated that the data is influenced by vibration of the carriage and towing post. Particularly, the towing post has been identified as the major source of problems during tests which try to simulate to the greatest extent possible the true forces acting on the ship at full scale.

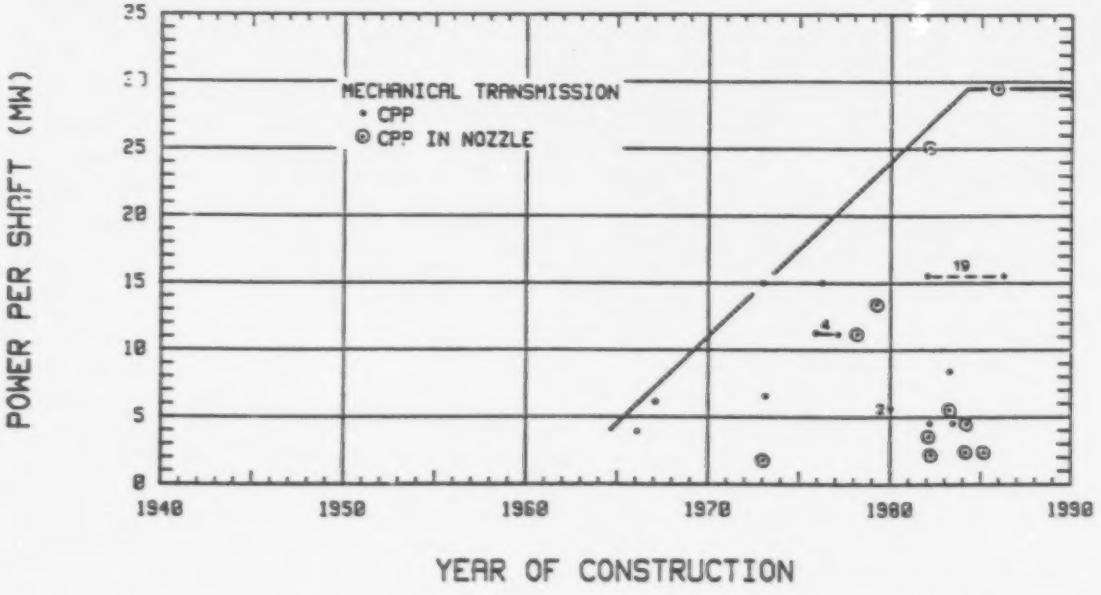
5.4 Propulsion

The propulsion characteristics of existing icebreakers and icebreaking cargo ships provides some insight on how the technology of icebreaking propulsion is changing. To illustrate several interesting points, power per shaft versus year of construction has been plotted in Figure 5.4.1. This parameter is plotted to illustrate any trends which may be apparent as icebreakers have developed since 1940. Icebreakers and icebreaking cargo ships are included and those ships with propeller nozzles, cp propellers and mechanical transmission, and various electric transmission are highlighted.

FIGURE 5.4.1

POWER PER SHAFT VERSUS YEAR OF CONSTRUCTION
FOR ICEBREAKING SHIPS





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The Figure shows the power per shaft increasing over time. Each increase appears to be driven by Soviet vessels, although the LEONID BRESHNEV was delivered two years after the slightly lower powered (power per shaft) POLAR STAR. In 1986 the power per shaft was dramatically increased by almost 100%, from 16.65 MW to 29.42 MW when the Soviet LASH vessel was delivered.

The selection of a suitable propulsion system for an ice class ship must be based principally on an analysis of the intended function of the vessel. The type of systems to be considered for such diverse ship types as dedicated icebreakers, bulk cargo ships, tugs, supply vessels, dredgers, etc., may be discrete to the mission profile and power requirement of the particular ship. Those systems which could seriously be considered are illustrated on Figures 5.4.2 and 5.4.3.

5.4.1 Propellers

Fixed pitch (FPP) and controllable pitch (CPP) have been fitted to Arctic ships. Fixed pitch propellers have been used for many years, and continue to be used on most icebreaking ships, although since 1966 controllable pitch propellers have seen increasing use on a wide range of icebreakers and icebreaking cargo ships. The relationship for some existing icebreaking ships between propeller power and diameter is shown in Figure 5.4.4, with FPPs and CPPs clearly identified, and the most interesting ships highlighted.

Irrespective of which propeller type is selected, the design requirements will depend on the vessels mission profile and will be more onerous than for non-ice transitting ships. The aspects which influence the design of Arctic ship propellers are;

- the loads and strength requirements,
- selection of materials, and
- the effect of nozzles.

From the present ship operation experience in the Arctic, the CASPPR propeller scantling requirements are seen to be sufficient in the lower ice class categories. However, it has been shown (Wind, 1983) that in the higher ice class/power categories, the CASPPR propeller scantling rules may not be adequate. This is made clear when comparing the CASPPR and USSR ice rules for propellers.

Most ice going CP propellers of bronze material are operating in nozzles whilst most stainless steel CP propellers in ice service are open propellers. Stainless steel generally has a higher erosion resistance, and a higher ultimate strength and yield strength then bronze material, thus allowing a more slender and efficient blade profile. The selection of propeller materials for recent Canadian icebreaking ships is illustrated in the following Table.

FIGURE 5.4.2

MEDIUM AND SLOW SPEED DIESEL ENGINE SYSTEMS
FOR ICEBREAKING SHIPS

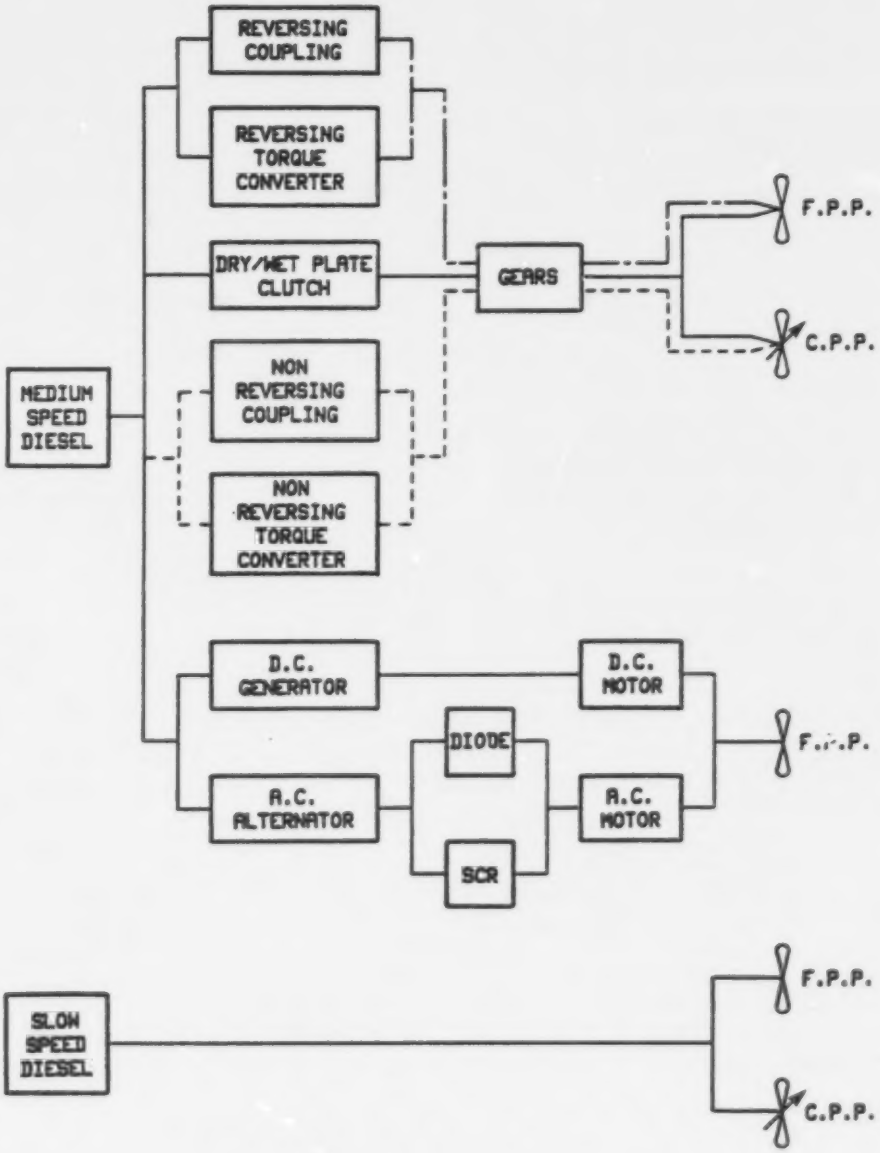

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FIGURE 5.4.3

STEAM AND GAS TURBINE SYSTEMS
FOR ICEBREAKING SHIPS

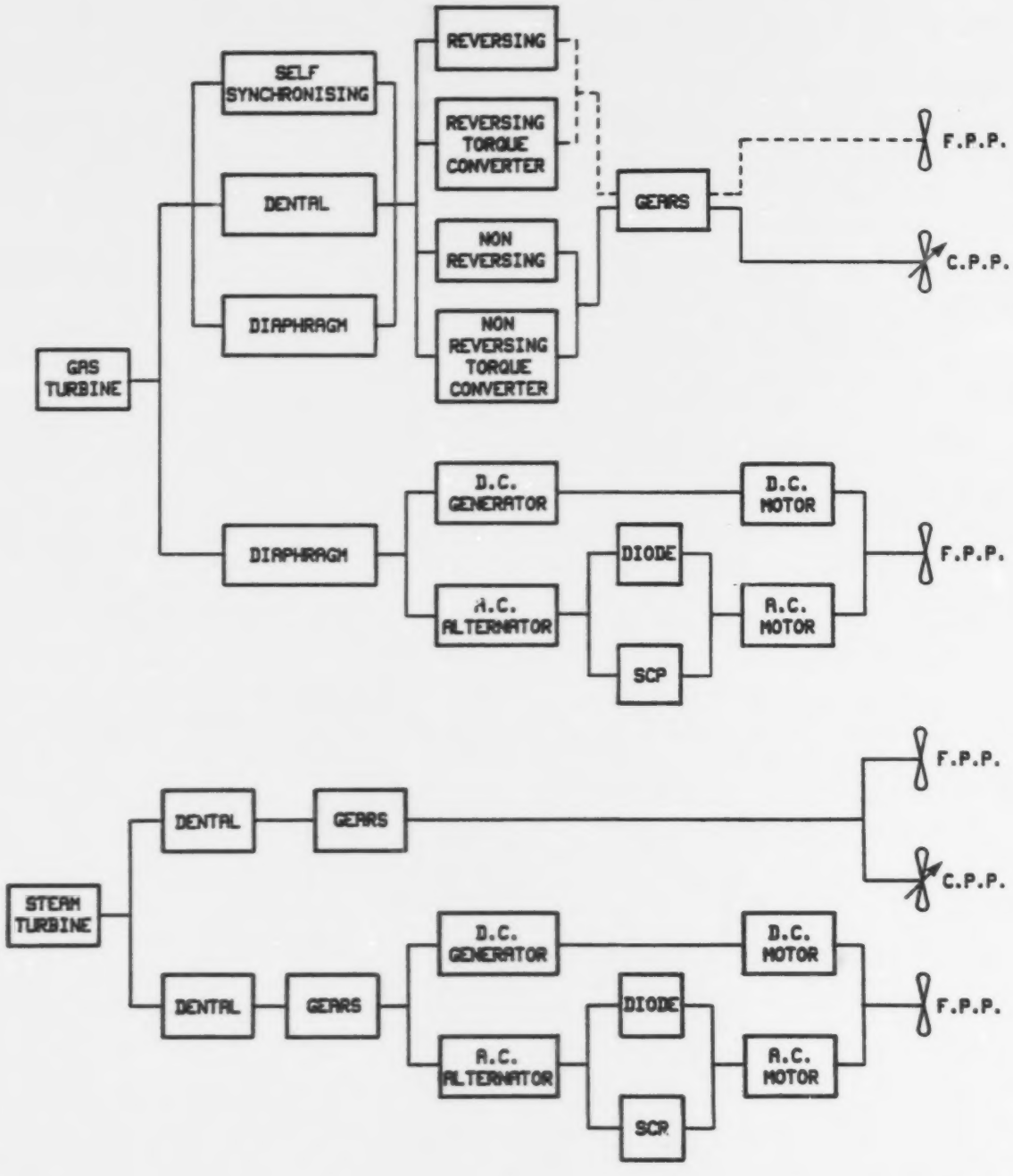

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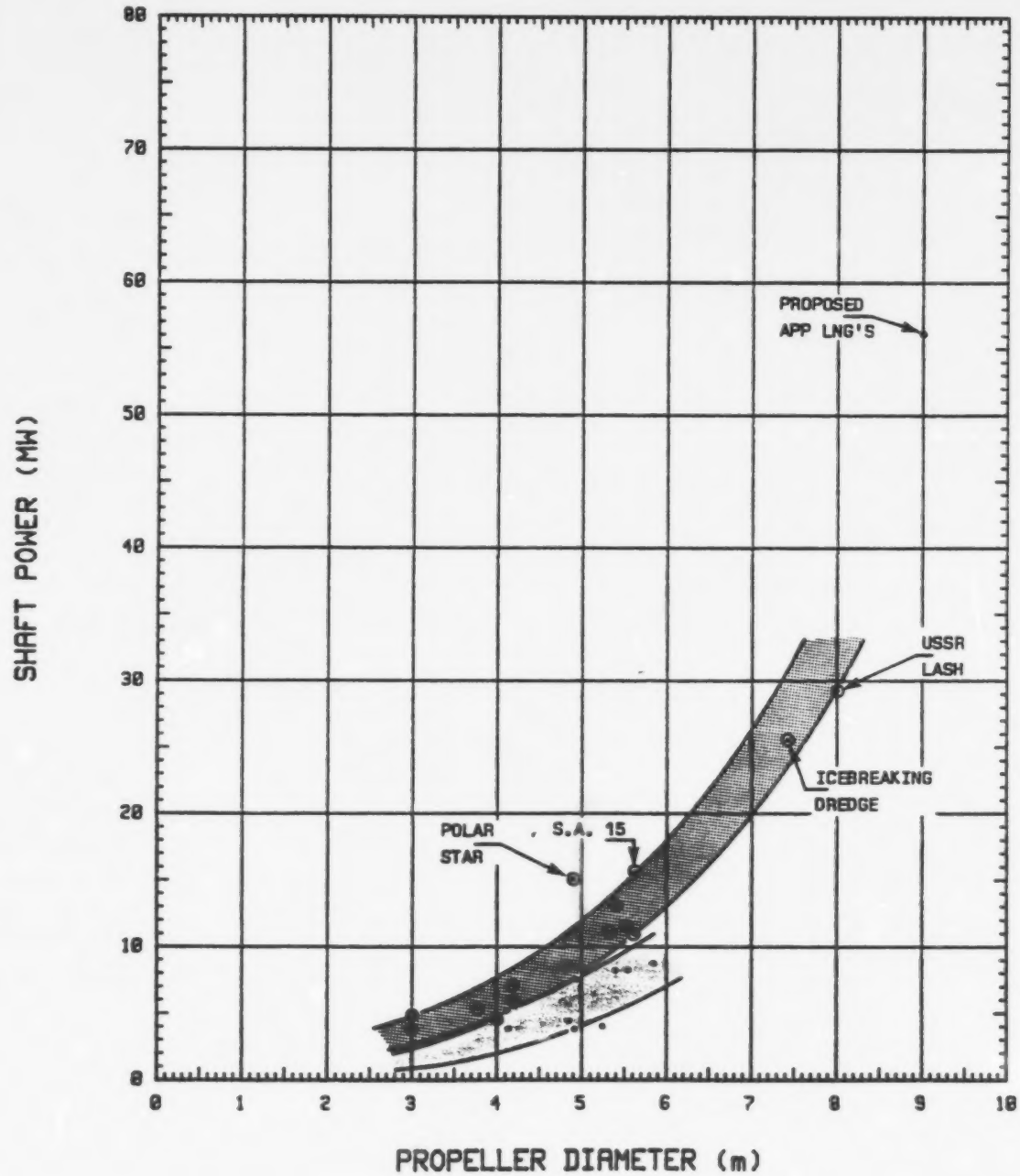
FIGURE 5.4.4

SHAFT POWER VERSUS PROPELLER DIAMETER
FOR ICEBREAKING SHIPS



. Fixed pitch
⊕ Controllable pitch

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Ship	Propeller Material
Arctic	Cunial Bronze
Kigoriak	Cunial Bronze
Robert LeMeur	Cunial Bronze
Terry Fox	Cunial Bronze
Radisson	Cunial Bronze
Arctic Ivik	Cunial Bronze
Ikaluk	Cunial Bronze
Polar Star	Stainless Steel

As can be seen from Figure 5.4.1 that there are a few icebreaking ships with nozzles. Those Canadian ships, such as Arctic and Kigoriak, which are equipped with nozzles have experienced successful operations with very few problems.

5.4.2 Shafting and Shaftline Components

The components of the power transmission system which lie between the propeller(s) and the motors or gearboxes are critical to the propulsion system's reliability. It is these components which may be exposed to problems due to increasing propulsion power. A growing body of experience is now available to guide the designer.

For very large Arctic class ships, high power and high torque will be required, resulting in very large diameter propeller shafts. The largest marine propeller shafts are fitted to a series of Seatrain tankers. These shafts are 1473 mm diameter and are fitted with 89 ton propellers driven through gearing at 101 RPM by 37 MW geared steam turbines. These shafts weigh about 160 tons. The maximum size of shaft which can be forged is based upon the maximum ladle weight which is presently limited to about 200 tons. This suggests that, depending upon length, a shaft diameter of about 1.6 metres may be the present maximum.

The diameter and materials of the propeller shaft of several icebreaking ships is identified in the following table.

		Propeller Shaft	
Ship	Shaft Power (MW)	Diameter (mm)	Material Yield Strength (MPa)
Arctic	11.08	610	215
Kigoriak	13.05	627	324
Terry Fox	8.65	775	300
Radisson	5.5	610	215
Polar Star	15	380	314
SA 15s	15.4	980	300
Polar Stern	7.34	380	ND

The most commonly fitted sealing system for propeller shaft bearings are radial lip seals. This seal has been used extensively in open water and Arctic class ships and has a proven record. The seal is particularly sensitive to shaft surface finish, rubbing speed, shaft eccentricity, shaft vibration, and to the pressure difference across the seal face. In

In general, shafts are made from forged carbon steel, although low alloy steel forgings are also used. In the case of icebreakers with oversized shafts, considerable weight saving can be achieved by using the higher strength of low alloy steel and in the case of the SHIRASE, over 100 tons were saved between three shafts (Sasaki, 1979).

Face seals for shafts up to 1600 mm diameter have already been tested and there appears to be few technical limits to extend the seal diameter to the largest sizes which could be accommodated on a ship. Face seals are used on the Canadian 'R' class icebreakers and on many of the Russian icebreaker and ice class ships.

The sterntube bearing is the most difficult bearing in the ship to design due to its imperfect operating condition. The sterntube bearing materials for several Canadian, USA, and USSR icebreaking ships are identified in the following Table.

Ship	Sterntube Bearing Material
Arctic	white metal (oil lub)
Kigoriak	cryselic resin (oil lub)
Terry Fox	cryselic resin (oil lub)
Radisson	rubber (fresh water lub)
Polar Star	rubber (salt water lub)
SA 15s	rubber (fresh water lub)

Intermediate shaft bearings must be 'full bearings', ie. the top and bottom halves must be similar, because in an extreme case of a transient load on the propeller the bearing could become top loaded instantaneously. The use of tilting pad type of bearings is favourable for the influence of bending moments, although in small vessels with a relatively low ratio of shafting stiffness to hull stiffness the advantage is small.

The tilting pad type of thrust bearing is successfully used in all applications and has proved to be reliable. It is also becoming common practice, for Arctic class ships, to install thrust bearings external to engines, or gearbox. The thrust block location on several icebreaking ships is identified in the following Table.

Ship	Shaft Power (MW)	Location Of The Thrust Block
Arctic	11.08	In the Gearbox
Kigoriak	13.05	In the Gearbox
Terry Fox	8.65	In the Gearbox
Polar Star	15.00	On the Propeller Shaft
S.A. 15s	15.40	On the Propeller Shaft
Polar Stern	7.34	On the Propeller Shaft

The major problem with thrust bearings, is Related to the maximum achieveable stiffness of the thrust bearing foundation. In conventional ships, thrust bearing foundation stiffness is of the order 200-400 tonnes/mm and to achieve higher stiffness will require an increase in the scantlings of the ships longitudinal structure.

5.4.3 Mechanical Transmission Components

As shown on Figure 5.4.1, since 1966, many icebreakers and ice class cargo ships have been fitted with direct drive propulsion systems and gears. All of these vessels are driven by one or more medium speed engines and single reduction gears, except for the Soviet LASH vessel which is driven by a steam turbine. These vessels are also fitted with controllable pitch propellers, some with the propellers in nozzles.

The recently delivered USSR SA15 cargo ships have fluid couplings fitted to the gearboxes, which limits the overload torque. Other ships are fitted with oversized flywheels on the shafting to smooth out transient ice torques and it is virtually standard practice for all ships fitted with diesel engines to be arranged to shed propeller pitch when the engine fuel rack is at a maximum to prevent engine stall. All medium speed engines are connected to the gears by means of a clutch, and for the vessels with fluid couplings, the coupling can also double as a clutch.

The components of mechanical transmission systems are critical to the successful operation of the vessel and these components must be evaluated to ensure suitability for the loads which are envisaged.

a) Gear Systems

Vessels which operate in the Arctic and are fitted with gears are of relatively low power and the design and manufacture of the gear sets are well within the experience of manufacturers. The largest gearboxes fitted to an icebreaker are the single input double reduction gears on the icebreakers POLAR STAR and POLAR SEA. These ships are powered by a combined gas turbine and diesel electric system, with each of the three gas turbines driving a double reduction gear box. The gas turbines are each rated at about 18.7 MW. The overload rating of the gears is not known, but the gas turbines under stall conditions can develop in excess of twice nominal torque and, unless protection is provided, the gears will have been so designed.

The largest gearboxes fitted to Arctic cargo ships are those on the USSR SA15s, rated at about 15 MW, with twin inputs, each of 7.5 MW. The engines are connected to the gears through two fluid couplings which permit full torque to be developed through the speed range of the propeller and limits ice loads to the engine. These gears are probably designed with an ice overload factor of 1.5.

There are many smaller gear sets fitted to Canadian vessels. The most interesting of these systems, on the Beaudrill vessels, have a large flywheel in the intermediate shaft aft of each gearbox. The flywheel has the effect of providing additional energy in the system to permit the system to ride through short transient overtorques with the minimum of speed loss and significantly reduces ice induced vibrations which might otherwise effect the gears (Motor Ship, Oct. 1983).

The largest marine gears, measured by torque capacity, have been constructed by Renk, West Germany. Triple input single reduction gears of 34 MW output, at about 110 RPM, have been built for container ships and are in service. The same company has constructed twin input gear sets rated at 25.6, 85 RPM, with an overload factor of 1.5, for operation in ice. The bull wheel for this gear is 4.4 metres in diameter, through-hardened and weighs 31 tonnes. This gearbox has not entered service but is equivalent to an open water rating of over 40 MW at an output speed of 100 RPM.

There is no theoretical limitation of the size and output torque for which a gear set can be built. However, experience suggests that gear development can safely take place only by increasing the maximum size by small increments.

b) Clutches

Friction clutches for marine use are designed as either wet or dry plate types and are actuated either by compressed air or hydraulically. These clutches have been used extensively in existing ice class ships which have medium speed diesel engines and gears. For large installations the wet plate clutch using sintered bronze clutch plates are generally preferred. While these clutches may be permitted to slip for a very short time, the very large heat produced when slipping must be dissipated by the oil coolers, and clutch plate distortion, due to the very high local temperatures, may occur.

Manufacturers claim that these clutches can be produced to any size by simply increasing the number of plates and the clamping force. The friction plate type of clutch has been proposed for ice class ships as protection devices for the engine to prevent stall by permitting the clutches to slip during overtorque. As far as is known they have not yet been used in this way.

c) Fluid Couplings

The use of fluid couplings in ships is limited by size. Couplings are only available to transmit relatively low torques and must therefore be fitted to a high speed element in the system which is normally the output

shaft of the engine. If a coupling is to be used in a torque limiting role, i.e. permitted to slip under over-torque conditions, very large hydraulic oil coolers must be fitted to dissipate the heat generated.

The torque ratio of a fluid coupling is 1:1 which means that the coupling does not aid the primemover in overcoming over-torques but does permit full engine torque to be applied at low propeller speed when the propeller is under stall conditions. The coupling has zero torsional stiffness and therefore very effectively isolates the primemover from down stream disturbances. This type of coupling is used in the Soviet SA15s.

The principle of operation of a torque converter is similar to that of the fluid coupling, except that a stationary element is introduced between the impeller and the runner. The output torque of the coupling increases rapidly for lower output speeds, becoming five to six times the input torque at stall. The output torque decreases with increasing output speed and becomes zero at the runaway speed.

d) Electric and Powder Type Couplings

Electric couplings have similar advantages to a fluid coupling and, in principle are similar to an induction motor. The coupling relies upon developing a torque by rotating a magnetic field around a squirrel cage winding. The couplings can be designed for very high torques at large slips and hence are similar in many respects to a fluid coupling. The efficiency of this coupling under normal operating conditions is about 97%.

The size of the couplings are usually up to about 3 MW and are fitted most often between a medium speed engine and a gearbox. As with fluid couplings they are torsionally compliant and reduce the effects of transient ice torques on the gears and engine.

5.4.4 Electrical Transmission System

Electrical propulsion systems are available in four types which, in chronological order of their development are; DC-DC, AC-AC, AC-DC and most recently AC-FFC-AC. AC-AC systems were in use as long ago as 1920 and recently in the second world war (T2 tankers), but these systems were relatively unsophisticated and did not have the speed control and low speed torque characteristics of the most recent systems which employ semi-conductor technology (Harrington, 1980; Stiglitz, 1984).

Although there are technical differences between the AC and DC systems for modern ships, AC systems are preferred because they are lighter, smaller and more efficient. The use of AC motors in preference to DC overcomes the problems of commutation which made DC machines more expensive to maintain and has limited the size to below 15 MW (Greene, 1983).

a) DC-DC Systems

This system is the one most commonly fitted to vessels with electrical propulsion systems, normally using medium speed diesel engines as primemovers, although steam turbines have also been used. Due to limitations of the commutator, the speed of DC generators and motors must be less than 1000 RPM and when turbines are used to drive the generators, reduction gears are used to reduce the size of the turbine and increase its efficiency (Harrington, 1980).

The major advantage of the use of DC systems is their basic simplicity, ease of control, good torque characteristics and their lower cost than other electrical system. The disadvantage of DC-DC systems are their high cost, weight and volume compared to mechanical systems, their low transmission efficiency of about 85% and their relatively high requirement for manpower for operating purposes.

b) AC-DC Systems

The AC-DC installation was developed to take advantage of the lower weight, lower cost and mechanical simplicity of AC generators with the simplicity, and precision of speed control of a DC motor. However, unlike the DC system, current flow cannot be reversed and therefore special provisions must be incorporated in the electrical system for manoeuvring.

The conversion of three phase AC to DC by the use of thyristors was introduced in the 1960's and was quickly adopted by designers of marine electrical propulsion systems. The use of thyristor control or SCR (Silicon control rectifiers) permits the use of 3 phase generators which can be arranged to supply power to not only the propulsion motors but to ship service consumers at the same time; the conversion from AC to DC can be carried out with low losses. It is this system which is now used in many icebreakers.

c) AC-AC Systems

AC-AC systems have been extensively used in the past. Early AC motors used for propulsion were of the induction type but these were replaced by synchronous motors with an induction motor winding for manoeuvring purposes. Control of these early machines was by frequency control through variation of the speed of the alternator.

The AC-AC, full frequency control (FFC) or cyclo-converter system is the most suitable AC-AC system, but is also the most expensive. Cyclo-converters have been fitted to the latest Finnish icebreaker OTSO, 7.5 MW per shaft, and has been ordered on the TAIMYR class of icebreakers 15 MW per shaft for the USSR (MER 1986). By this means the motor can be controlled precisely and steplessly by a highly reliable static control system.

AC-FFC-AC systems are technically superior to AC-DC and DC-DC systems due to their higher transmission system efficiency and their nearly indentical torque characteristics. There are no upper limits of the theoretical size of the alternators although motor dimensions and weight would influence the actual size of motor which could be fitted into a ship. Two 44 MW motors are presently being fitted to the liner QE II.

5.4.5 Primemovers

No primemover used for ship propulsion exhibits all of the important characteristics of: reliability; flexibility; maneouvrability; and robustness, although primemover characteristics can be modified by the use of suitable transmission systems. The prime movers which have been installed on existing icebreaking ships are shown on Figure 5.4.5, plotted as power per shaft and total power versus year of construction.

a) Gas Turbines - Aero

Experience of the use of Aero gas turbine engines in the Arctic is confined to two vessels; the USCG icebreakers POLAR STAR and POLAR SEA. These ships are each fitted with three Pratt and Whitney FT4 aero-engine derivative gas turbines, each of which drives a controllable pitch propeller through a gearbox. The engines operate with diesel fuel and are only used for heavy icebreaking; medium speed diesel/electric power is used for cruising and light icebreaking.

The greatest advantages of gas turbines over other propulsion engines are the very high power to weight ratio, the compactness of the turbine installation and the low fitting out cost which is reflected by the lower overall capital cost of the ship. The greatest disadvantages are the very high fuel consumption especially at off-design conditions, the cost of the fuel, and the maintenance requirements.

b) Gas Turbine - Industrial

The CCGS icebreaker NORMAN MacCLEOD ROGERSs was fitted initially with two Westinghouse Model W21 industrial gas turbines, designed to operate with diesel fuel, each driving a DC generator in parallel with medium speed diesel driven generators. These gas turbines have been replaced by conventional medium speed diesel engines due to the high fuel cost of the gas turbines.

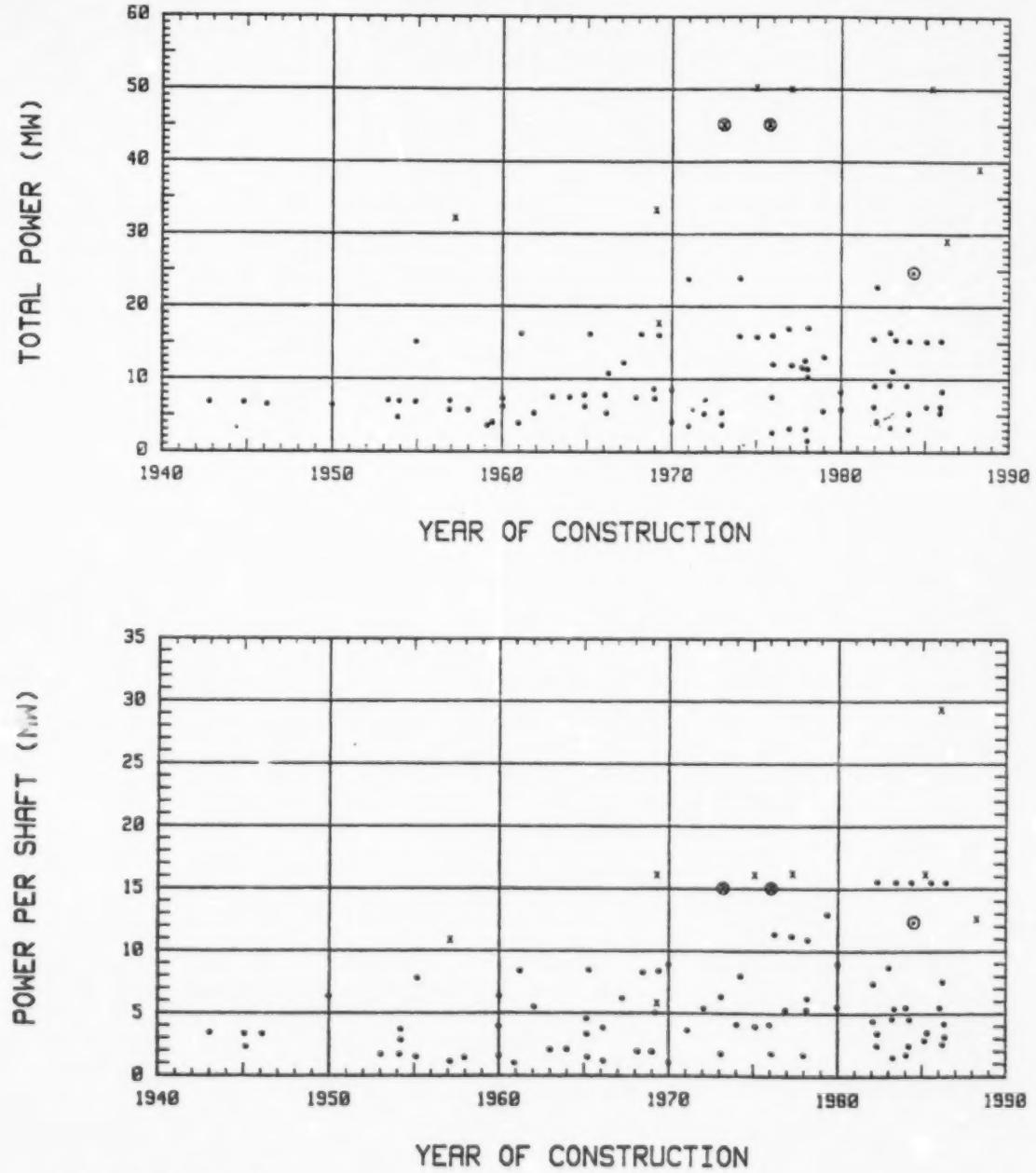
c) Steam Turbines

Steam turbines can be constructed for virtually any power requirement. Machines for electrical power generation in land plants exceed 1000 MW. The largest units built for ship propulsion are rated at about 50 MW but this limit is related to the power which can be absorbed by the propeller and not a limit imposed by the engine. Marine steam turbines with output power in excess of 100 MW have been proposed (MacDonald, 1977).

There are very few icebreakers fitted with steam turbine systems. The Canadian icebreaker CCGS LOUIS S. ST-LAURENT is fitted with a 20 year old

FIGURE 5.4.5

PRIME MOVERS INSTALLED
ON ICEBREAKING SHIPS



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steam turbine electric system, and oil fired boilers, and the USSR nuclear fueled icebreakers are fitted with more modern steam turbine systems. The most recent steam turbine vessel to be built is a LASH type barge carrier for the USSR for Arctic service. This ship is powered by cross compound turbines rated at 30 MW arranged to drive a controllable pitch propeller through double reduction gears. The steam turbine is to be powered from steam generated by a nuclear fueled boiler.

d) Medium Speed Diesel Engines

The most popular engine for the propulsion of icebreakers and ice class cargo ships is the medium speed diesel. This popularity is based primarily upon the engine's compactness, light weight, full efficiency and good reliability. Its disadvantage for use in ice class ships is the lack of significant overtorque capacity.

This type of engine has been fitted to many icebreakers using diesel electric propulsion. The use of electric transmission permits high torques to be developed through the speed range of the propeller and clamps ice torques being transmitted to the engine. Some of the direct drive systems are fitted with fluid couplings between the engine and gearing allowing full load torque to be developed at reduced propeller speed. Both the electric transmission system and the fluid coupling will prevent engine stall under the most severe propeller overload condition. The USSR cargo vessels SA15 are fitted with fluid couplings between the engines and the gearbox.

It is expected that medium speed diesels will continue to be the preferred engine for Arctic ship propulsion for all vessels required in the immediate future.

e) Slow Speed Diesel Engines

The slow speed diesel engine is the only prime mover which has been specifically developed for ship propulsion. All present day engines of this type operate on the two-stroke cycle, are cross head engines and are reversible. The engines are designed to be directly coupled to a fixed pitch propeller although some engines have been fitted with controllable pitch propellers.

The USSR LASH ship Alexsei Kosygin is the only Arctic class icebreaking ship in which this type of engine is fitted. In this ship, two 7 cylinder B&W engines are fitted, each of about 13.4 MW, which each drive fixed pitch propellers. There have been no reports of how the vessel performs in ice.

f) Combined Drives

The only Arctic class vessels fitted with combined systems are the USCG icebreakers POLAR STAR and POLAR SEA. These ships have three Pratt and Witney FT4 aero-derivative gas turbines each driving a controllable pitch propeller through reduction gears, and a diesel electric propulsion system. The gas turbines are intended for use when full power is required,

such as heavy icebreaking, and the diesel electric system for use when cruising or for light icebreaking. The systems do not operate together. This is a good example of making use of two different systems for widely different power requirements in the overall interests of economy.

Future Arctic class ships with very large power requirements for the most severe icebreaking conditions are ideal candidates for combined drives. Mission profiles of Arctic ships indicate that maximum power is required for only a limited period of time and the propulsion system must be sufficiently flexible to enable that power to be developed at maximum possible efficiency. As the power requirement rises this need for efficiency becomes greater due to the potential fuel savings.

5.4.6 Information Deficiencies

The deficiencies in relation to propulsion are in the areas of the design loads which may be expected, the methodologies for designing system components to these loads, and the limitations of present manufacturing technology. It is these areas which govern the size and therefore economics of propulsion machinery, and as a result will have most influence on the viability of future Arctic shipping systems.

a) At present, CASPPR and the rules of the classification societies use the Finnish-Swedish ice class rules as the model to calculate the shafting diameter for Arctic class ships. This formula is empirical in nature and developed to suit the needs of relatively small and less powerful ships.

   The various rules used to calculate shaft size should be examined for various sizes and classes of ships, and for various propeller weights. Using the calculated shaft size and the assumed propeller weight, the shafting principal stresses should be determined using agreed ice overload factors to ensure that sufficient margins or safety factors are provided by the formulas.

b) Medium speed diesel engines are technically the least favourable engine for Arctic service due to poor over-torque characteristics and the potential for overload when ingesting very cold air. There is also a certain amount of evidence to suggest that engine pistons and liners may experience a higher rate of wear when operating in the Arctic that in more temperate waters. Operating experience should be investigated to ascertain the extent of these problems.

c) There is considerable reluctance on the part of operators to burn heavy fuel in engines which operate in the Arctic. However, there is no theoretical reason why heavy fuel should not be burnt in these engines provided procedures are followed. At least one Canadian vessel habitually operates with heavy fuel in the Arctic. If operators can be convinced that heavy fuel operation can be successful and economical, a considerable saving can be made in the cost of bunkers and preservation of high grade fuel resources.

d) Icing of intakes to the engine room and engine has potentially serious consequences. It may cause engine damage, cause the engine to stall and endanger the ship, cause blow back from boilers and even cause a sufficient pressure loss in the engine room to result in damage to bulkheads.

e) An important parameter to be determined when designing a propulsion system for Arctic class ships is the loads on the propeller and shafting system brought about by ship/ice interaction. There is very little knowledge of the actual loads. The guidance provided by the CASPPR and classification societies rules are not based upon present day evidence and knowledge.

The design loads for the propellers of Arctic ships should be based on both full scale measurements from existing ships and modern theory. Ice loads related to ice class, ship length and draft and propeller type and protection should be proposed with the intent to provide the designer with more reliable guidance and to update the present regulatory approach.

f) The shafting loads can be increased due to the influence of ice entrained in the propeller. The additional load will be additive to normal shafting and sterntube bearing loads and may prove to be significant. At present there is no requirement by the rules to consider added mass due to ice (although in rational alignment calculation added mass due to water is allowed) and there is no requirement to consider the influence of propeller ice loads on shaft line bearing loads, the assumption being that a sterntube bearing length (for an oil lubricated white metal line bearing) of 1.5 D will provide a sufficiently large bearing area.

g) The problems of transmission, to the primeover, of axial displacements due to thrust bearing deflection must be studied to determine the true extent of this problem.

h) If ice ingestion by the propeller can be minimised, the design ice load requirement of the propulsion system can be reduced. At present there are no regulatory allowances to reduce the size of the propeller components to take into account the possible benefits of devices which may protect the propeller from ice loads.

i) Propeller shafting external seals are essential for oil lubricated bearings, and the continued efficiency of the shaft sealing system are wholly dependent upon shafting rubbing speed, shaft surface finish, shafting roundness, shafting stability and lack of axial movement of the shafting in the seal. The efficiency of this type of seal quickly diminishes as shafting diameter increases. The limitations in the use of shaft seals, both lip and face type, should be investigated.

j) In the present rules there are regulations specifying the machinery system in terms of ice torques but no regulations which specify the ice thrusts to be used. The probable over-thrusts for ice class ships should be assessed with a view to inclusion in the Regulations.

k) For large ships with high power, the size of shaftline components will increase beyond present manufacturing experience. There are dangers in increasing sizes regardless of the influence of size on quality and reliability. The present limitations in the manufacture of shaftline components, seals, bearings, shaft length and diameters, couplings, etc. should be determined along with the means of ensuring that quality standards can be reliably met when size is increased above present experience.

l) Regulations describe gearing transmission systems only in terms of over-torques, although factors such as alignment during ice load excursions, shock loads, over-torques under maximum stall conditions and other parameters are fundamental to the efficient operation of a gearing system.

m) Although the present CASPPR requires that the gearing of Arctic ships is to be specially protected from over-torques, this regulation is not applied as there are no known methods to carry out the intent of the regulations. However, the intent to protect the gearing from overtorques should be pursued and practical methods by which this can be achieved should be identified.

n) As gearing size increases, both physically and with respect to torque, the gear manufacturer has various choices to make. Either gear diameters must increase, gear tooth length increase, the K factor increase or a combination of all three parameters. Increases in these parameters should not be considered without a full understanding of the penalty, if any, and the compromises which may be required.

o) The parameters essential to the specification of a reliable gear design should be documented in order that the limits, if any, which presently exist to increasing gear size above present practice, can be understood.

5.5 General Outfit and Auxiliary Systems

The Arctic environment has an effect on virtually all items of equipment or systems onboard a ship. The equipment or systems which are most effected are:

- Deck machinery and equipment
- Mooring systems
- Steering systems
- Sea suction arrangements
- Ballast tank heating
- Lifesaving equipment
- Firefighting systems
- Icing protection
- Coatings
- Accommodation

The designer and operator must deal with problems in each of these areas, and the final design must couple the need for an efficient system with the constraints imposed by commercial considerations.

5.5.1 Deck Machinery

The major items of deck machinery and associated equipment which may be effected by the Arctic environment are:

- anchor windlasses
- mooring winches
- cranes
- hatch covers

The deck machinery presently being used on Arctic ships has generally performed adequately. Experience has been gained with all of the major system types and, while there are specific benefits associated with each option, all appear to be technically acceptable. Special care must be taken with the choice of materials, hydraulic oil and lubricants, and with the protection of equipment against mechanical damage. Protection from ice accretion and means of de-icing must be considered, and the protection of personnel during outdoor operations will be important for year round operations in the Arctic.

5.5.2 Mooring Systems

Mooring systems for Arctic ships must accomplish the same functions as those on non-Arctic ships. However, the unique environment places demands, not present for other ships, on both the equipment and operators.

The most suitable synthetic fibre rope material appears to be 'polyester' (terylene). It stands up well to the effects of strong sunlight and is unaffected by very low temperatures. Although heavier than other fibres it can still be handled quite easily, particularly when drum mounted on a tension winch. Eight strand multiplait ropes remain the most pliable at very low temperatures.

5.5.3 Steering Systems

Typically, the steering gear will be of the electro-hydraulic type, utilising electrically driven variable delivery pumps to deliver oil to rams working in hydraulic cylinders. The rams are arranged to operate the tiller which is keyed to the rudder stock. Depending on the design, the systems may be of the two or four ram type with single or double acting rams. The following ships are fitted with a two ram double acting system:

- CCGS Pierre Radisson (R Class)
- M.V. Canmar Kigoriak
- M.V. Robert Lemeur
- M.V. Terry Fox/Kalvik
- M.V. Ikaluk/Miscaroo
- M.V. Arctic

The present practice on Arctic ships is to support the rudder at top and bottom with pintles and bearings. In the case of many icebreakers, several pintles are used to attach the rudder to a rudder post, which in turn is attached at the top and bottom to the ship's sternframe. The more standard arrangement used on open water ship's is to have an upper bearing and a lower pintle ie, only two supports. This arrangement is now being used on icebreakers and other ice capable vessels.

Protection of the rudder, particularly when a ship is moving astern, is usually provided in the form of an ice horn or by an ice deflecting stern shape.

Experience with electro-hydraulic steering gears on icebreaking ships has been good. Although some statistics have been assembled on steering system damage (Menon, 1979) very little data exists on which to determine if the steering systems on Arctic ships are more at risk than those on non-Arctic ships.

Most of the regulatory authorities and classification societies have adopted a similar approach to the minimum requirements placed on the steering systems of Arctic ships. However, none of the regulatory requirements consider the duration of rudder/ice interaction. It has been believed that fast acting relief valves could react quickly to eliminate the effect of high torques, thereby negating the need to use those high values as system design criteria. However, the duration of the rudder/ice interaction can be less than 0.1 second, possibly too fast for relief valves to have any effect.

Notwithstanding this, the low incidence of damage to steering gears indicates the success of the present design requirements. However, it must be recognised that Canada presently has no year round operating capability in the Arctic and that future ships may be faced with more onerous operating conditions. Present practice may prove to be inadequate for high Arctic class ships which must manoeuvre in multi year ice.

5.5.4 Sea Suction Arrangements

The clogging of sea suctions is a common operational problem on Arctic ships, particularly ships with a light draft. The ice either blocks the inlet grill or, more commonly, enters the sea bay and blocks the suction pipe directly. Either event will result in a rapid increase in temperature of the cooling system water and a main engine shutdown or reduction in power level. Solutions have been developed to maximise the efficiency of the sea inlet boxes, although these solutions are not always implemented on modern ships.

5.5.5 Ballast Tank Heating

The freezing of ballast water has been and continues to be a problem. There is no doubt that care should be taken to locate ballast tanks away from the cold air, but the decision to install costly systems to heat the contents, piping systems or valves must be considered in the light of real experience. The problems may be resolved by more appropriate tank location or by the design of simple anti-icing or de-icing systems.

The practical solutions which have been considered for heating the ballast water are; steam heating coils with the condensate return piping run through a dry duct keel, thermal fluid coils, recirculation of main propulsion cooling water through the ballast tanks, and continuous recirculation of all ballast water through the ship.

5.5.6 Lifesaving Equipment

The survival of personnel who abandon ship in Arctic waters will depend to a large extent on the type and quality of lifesaving equipment provided and the time before rescue. Of particular importance is:

- suitability of the equipment to prevent the survivors from drowning in a variety of conditions ranging from open water to closed pack ice.

- the type of clothing provided to insulate survivors from the extreme cold both when dry and when wet.

- the type of shelter and the ingenuity of survivors to improvise as required.

The unique nature of the Arctic environment requires that special consideration be given to crew survival. The present regulations provide only for ship abandonment in open water with no special consideration given to the Arctic. Research has been performed recently identifying the shortfalls of the equipment presently carried onboard ship, and further development and testing of survival equipment and supplies has been arranged.

5.5.7 Firefighting Systems

The firefighting systems normally installed on Arctic ships have been based largely on the experience gained on non-Arctic ships. The special problems encountered relate to the cold air temperature and to the the icing of fire fighting equipment.

Firefighting systems on Arctic ships must be carefully designed to ensure efficient operation in extremely cold air temperatures. Some systems such as dry chemical powders are uneffected by these extremes but the water, foam, and to some extent the gaseous systems are adversely effected. The effectiveness of each of these systems has yet to be demonstrated during a major fire onboard an Arctic ship.

5.5.8 Icing Protection

Ice accretion on the decks, superstructure and equipment of ships is normally caused predominantly by ocean spray (AES, 1985; Stallabrass, 1980). In the eastern Arctic the causes are divided between ocean spray (57%), fog (33%), and rain (10%). Statistics in the western Arctic are similar. As with ships in general, the effects of icing on Arctic ships are to decrease the ship's operational efficiency, particularly in relation to the use of deck equipment such as mooring systems and cargo hatch

covers. There are also serious safety implications if lifesaving equipment or fire hydrants or radar antennae becomes inoperable due to ice accretion.

The most likely solution to icing problems is a combination of design features aimed at; a) reducing the number of sensitive areas, b) protection of those areas and, c) the supply of means to de-ice the equipment which cannot be otherwise protected.

5.5.9 Coatings

The choice of coatings, for ships which operate in the Arctic, depends on the mission of each ship. For topside areas, chlorinated rubber paint is commonly used due to it's cold temperature properties. Below the waterline, the problems of hull abrasion and the search for a low friction coating have resulted in many research programmes. The outcome is a better understanding of the nature of hull/ice interaction, and coatings which appear to satisfy both requirements. Inerta 160 and Zebron, particularly Inerta 160, are now commonly used on icebreaking ships.

5.5.10 Accommodation

An investigation of accommodation requirements (Melville, 1984) surveyed the opinions of Arctic seafarers on the accommodation facilities on the vessels in which they have sailed. The seafarer's response highlights noise, vibration and recreation facilities as areas of concern, but the other aspects, such as cabin size and climate, are acceptable as presently constructed.

5.5.11 Information Deficiencies

The deficiencies in relation to general outfit and auxiliary systems cover a wide range of equipment and systems. Of most importance is the effect of ice on the requirements of steering gears. This is a subject of great concern to ship safety and should be given a high priority. Other areas of interest relate more to improvements in the practicality of the ship design from the operations veiwpoint.

a) The deck machinery presently being used on Arctic ships has generally performed well. Experience has been gained with all of the major system types and, while there are specific benefits associated with each option, all appear to be technically acceptable. Special care must be taken with the choice of materials, hydraulic oil and lubricants, and with the protection of equipment against mechanical damage. Important aspects include:

   - the protection of deck equipment from icing and the design of de-icing systems.

   - the design of enclosed mooring flats where the working environment can be controlled, and the design of equipment shelters for the open deck.

   - the extent of which low temperature materials are necessary in deck equipment.

b) The mooring systems presently used on Arctic ships are similar to those on non-Arctic ships, and appear to have performed satisfactorily. However, consideration is now being given to enclosed mooring flats, strain gauging the mooring lines to measure forces acting on the ship, and using polyester as a material for the mooring lines. The deficiencies in our knowledge of mooring systems relate mainly to the forces acting on the ship when moored in a variety of situations.

c) The design requirements for steering systems depend on the main dimensions and mission of the ship being considered. Ships which are long and deep are less likely to expose the rudder to severe ice interaction than short and shallow draft ships which may be used for aggressive ice management duties. Presently the design requirements which are enforced by the regulatory authorities are minimum standards.

   Present practice may prove to be inadequate for High Arctic ships which must manoeuvre in multi-year ice. Only a greater understanding of the rudder/ice loads, and of how these loads are absorbed by the steering gear system, will give confidence that the present design requirements are still acceptable. Important aspects include:

   i) The protection of the rudder from ice loads by innovative stern design, without detracting from the ship's hydrodynamic or icebreaking performance.

   ii) The magnitude and effect of rudder/ice interaction on each element of the steering system.

   iii) The way in which the steering system should be designed to accommodate the actual loads.

d) The efficient operation of sea inlet boxes is of great importance to Arctic ships. The main engine cooling system is normally fed directly from these boxes and any blockage will allow the cooling water temperature to rise above the permissable level. Solutions have been developed to maximise the efficiency of the sea inlet boxes, although these solutions are not always implemented on modern ships. The only major deficiency in the present understanding of how to deal with this problem is how the sea box grills of shallow draft ships may be kept free of slush ice.

e) Our present knowledge of probable icing conditions in the Arctic is very limited. Little attention has been given to the problems caused by the icing of deck equipment or of safety and evacuation systems. Anti-icing and de-icing systems must be developed to ensure personnel safety and to increase ship efficiency. Experiments should be designed and carried out to aid in developing anti-icing or de-icing systems which are practical for Arctic ships.

f) The choice of coatings, for ships which operate in the Arctic, depends on the mission of each ship. For topside areas, chlorinated rubber

paint is commonly used due to its cold temperature properties. Below the waterline, the problems of hull abrasion and the search for a low friction coating have resulted in many research programmes. The outcome of these programmes is a better understanding of the nature of hull/ice interaction and, coatings which appear to satisfy both requirements. The deficiencies in our present knowledge of hull coatings and their application may be summarised as:

i) The location of hull areas where most of the ice impacts and abrasion occurs.

ii) The true hull/ice friction factors, and the operating conditons of the coating, in terms of load versus time and frequency.

iii) The cost benefits of installing the more expensive coatings required by the Arctic environment, as a function of the maintenance requirements.

g) The accommodation facilities required on Arctic ships are in many ways similar to those on non-Arctic ships, although the severe climate of the Arctic does impose design requirements in regard to air temperature. These requirements will be reflected in such areas as insulation, climate systems, and vibration control measures. The deficiencies in our present knowledge relate to how noise and vibration can be reduced effectively to acceptable levels.

6. POTENTIAL SHIPPING SYSTEMS

The focus for the review of the state-of-the-art of Arctic ship technology is currently known and available technology. To evaluate the important deficiencies which are present in this technology requires an assessment of future requirements. This section of the report provides the link between the deficiencies identified in the previous sections and the optimization and research sections which follow.

A separate report was prepared entitled 'Probable Arctic Shipping Scenarios To The Year 2000' (Melville, 1986) which examined the future of Arctic shipping. This report concluded that opportunities for future vessels existed in three areas;

- oil and gas development
- mineral development
- government activities.

The first two areas of activity were reviewed in some detail with current and potential developers of these resources. There are only a few possible developments which could involve ships to transport the resource, and production from each will be dependent upon improved markets or government support.

The governments shipping activities in the Arctic are currently seasonal and are under the mandate of CCG. Their presence and activities are driven by the community requirements, commercial shipping activity and government policy, and the levels of community requirements and commercial activity will only change should resource development occur. Government policy can create demands such as the proposed Polar 8 which may lead to commercial development, but speculation in this area was beyond the scope of this study.

The study reviewed each of the potential projects and, by exercising some judgement, presented the 'most probable' Arctic shipping scenarios. These scenarios are described in Table 6.2.1 and in the following notes, the projects are divided into year-round and seasonal projects in Figures 6.2.1 and 6.2.2.

Considering the most probable projects, it is only the large scale Beaufort Sea oil project, the high Arctic oil project, and the Arctic Pilot Project which are large enough to require very large vessels. In each of these cases, 200,000 dwt oil tankers or 140,000 cu m LNG carriers (equivalent in size to a 200,000 dwt oil tanker) could be the preferred mode of transportation. The economics of using vessels of this size will undoubtedly be better than smaller vessels but the vessel size requires very high propulsion power and structural strength, raising questions of reliability.

Optimisation of the configuration of these systems is therefore complicated by issues of technology. It is not acceptable to look only at the economics of ships of various sizes and settle on the system with least overall cost, unless the evaluation can somehow include the economic effect of system downtime for ship repair. Risk and reliability models have been

TABLE 6.1

PROBABLE ARCTIC SHIPPING REQUIREMENTS

LOCATION	CARGO TYPE	ANNUAL VOLUME (TONNES)	SHIPPING SEASON CONTEMPLATED	PROJECT LIFE
MINERALS				
Nanisivik*	lead zinc	125-150,000	July - November	5-8 years
Polaris*	lead zinc	225-300,000	August - mid October	15 years+
Heninga Lake	zinc, copper gold, silver	125-175,000	June - mid October	10 years+
Izok Lake	lead zinc	200-300,000	mid July - mid October	15 years+
OIL AND GAS				
Bent Horn*	oil	13-70,000	August	3 years+
Beaufort Sea	oil	20-50,000	August - mid October	8 years+
	oil	50-500,000	July - November	8 years+
	oil	4-6 million	year-round	10 years+
	oil	1-1.5 million	year-round	10 years+
High Arctic	oil	2-2.5 million	year-round	20 years+
	gas	3-3.5 million	year-round	20 years+

* Operating Projects

FIGURE 6.1

YEAR ROUND SHIPPING OPPORTUNITIES
TO THE YEAR 2000

PROJECT	ICE CAPABILITY	VESSEL SIZE	SHIPS REQUIRED
BEAUFORT SEA OIL			
1. SMALL SCALE YEAR-ROUND	MULTI-YEAR	50,000 DWT	1
2. LARGE SCALE YEAR-ROUND	MULTI-YEAR	200,000 DWT	2+
HIGH ARCTIC OIL			
3. CISCO (SMALLER VESSELS)	MULTI-YEAR	100,000 DWT	2+
4. CISCO (LARGER VESSELS)	MULTI-YEAR	200,000 DWT	1+
HIGH ARCTIC GAS			
5. ARCTIC PILOT PROJECT	MULTI-YEAR	2 x 140,000 CU M	2+

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FIGURE 6.2

SEASONAL SHIPPING OPPORTUNITIES
TO THE YEAR 2000

PROJECT	ICE CAPABILITY	VESSEL SIZE	SHIPS REQUIRED	SEASON
MINERAL PROPERTIES				
1. IZOK LAKE	FIRST YEAR	20-30,000 DWT	1+	AUG - OCT
2. HENINGA LAKE	FIRST YEAR	20-30,000 DWT	1+	JUN - DEC
3. NANISIVIK	FIRST YEAR	20-30,000 DWT	1+	JUL - NOV
4. POLARIS	FIRST YEAR	20-30,000 DWT	1+	AUG - OCT
BEAUFORT SEA OIL				
5. SEASONAL PRODUCTION	MINIMAL	20-50,000 DWT	1+	AUG - SEP
6. EXTENDED SEASONAL PRODUCTION	FIRST YEAR	20-50,000 DWT	1+	AUG - OCT
HIGH ARCTIC OIL				
7. BENT HORN	FIRST YEAR	20-30,000 DWT	1+	AUG

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developed in other industries to take into consideration this very important issue, but these models in the shipping industry are in their infancy.

The probable Arctic shipping scenarios described above lead to the conclusion that large Arctic ships may be required in the near future, and that the issues of Arctic ship technology which relate to ship size should be fully explored to determine where deficiencies in the present state of the art would limit the size of ship which could be built. Similarly, where optimisation of ship components can reduce the capital or operating costs, every effort should be made to understand the ramifications, particularly when the proposals would require components which are larger or radically different than has been previously constructed.

7. OPTIMISATION AND RECOMMENDED RESEARCH

7.1 Introduction

The review of Arctic ship technology contained in the preceeding sections addresses separately each aspect of designing and operating ships, although recognising that there is a clear link between 'design' and 'operations', and between these and the changing environment. The ability to design for a given set of environmental conditions is seldom in doubt. Similarly, although with less certainty, the expertise presently exists to operate ships year round.

These abilities relate to: the size of the shipping system; the size of the systems components; the locations to be served; the season of operation; and the ability to extrapolate safely and reliably from known technology. It has been demonstrated that the solution(s) to these problems of system configuration are changing with every breakthrough in technology and every extension of the operating season. Examples of this are the success of the Beaufort Sea vessels and the most recent success in the eastern Arctic of the ARCTIC.

The process of solving these shipping system and ship configuration problems can be referred to as 'optimisation'. Although the perception of the optimum solution is changing with experience, a particular shipping system will be tied to the understanding of Arctic ship technology at a point in time. Even recognising that limits may exist in the construction and operation of these ships, there are many options open which may greatly effect a project's overall economics. It is the search for the most economic, yet safe and reliable system, considering the total mission profile, which can properly be referred to as optimisation.

It is also clear that shipping systems are planned many years ahead of the proposed operating period, placing on the designers and operators the additional burden of anticipating developments in design, manufacture, construction and operating capabilities. It is for this reason that a research programme should be initiated to explore all of the benefits and liabilities of solutions which would extend the present boundaries of these capabilities.

7.2 Optimisation

The optimisation of a ship's design can be pursued from several directions. An optimum design can be quite different depending on the importance given to the parameters which are subject to optimisation. For example, the parameters which may be used are:

- open water performance,
- performance in level ice,
- minimum fuel consumption,
- minimum capital cost,
- minimum operating cost,
- minimum life cycle cost.

Several, if not all, of these parameters are in conflict. While it is possible to design the ship for any of the parameters, the combination of two or more will result in the need for compromise. Optimum open water performance cannot be obtained without sacrificing performance in ice and vice versa. Similarly, minimum fuel consumption and operating cost implies a design with low resistence in ice which leads to narrower breadth and increased length resulting in a higher capital cost.

This optimisation process is, in fact, more an exercise in decision making, in each of the major areas of the ship's design. Irrespective of whether the process is called 'optimisation' or simply 'design', there exists the potential for large life cycle cost savings if the full extent of the state of the art is applied and if the state of the art is expanded in several key areas.

7.3 Recommended Research

7.3.1 Rationale

The level of understanding of the requirements which are imposed on Arctic ships, has increased tremendously over the last few years. The historical data on existing ships illustrates the number of icebreaking vessels and offers some insight into how the technology is changing with time. The years between the mid 1970's and mid 1980's have produced a wealth of full scale data and a number of innovations.

It is equally clear that, although much has been achieved, much is still to be done. There are many areas of the technology where very little is known. When these deficiencies are placed in the context of the most important single parameter for commercial Arctic shipping, economics, it is possible for them to be priorised ie, organised in terms of timeframe and the resources which should be allocated towards finding solutions.

It may not be possible to reduce everything easily to economic terms. Some problems relate more to practical operational concerns, which could be solved by appropriate design if sufficient information were available on the problem.

The following text presents a programme of recommended research which is focussed on the areas of Arctic ship technology where; a) dramatic improvements in transportation efficiency are possible, and b) improvements in the safety and practicality of Arctic shipping are possible. In compiling the list of recommended research projects, the information presented in each section has been reviewed to determine where deficiencies exist. These deficiencies have been assessed against the criteria described above, and those items of research which would be of most benefit to the future development of Arctic shipping have been retained.

7.3.2 Environment

Based on the review of Arctic ship technology, as it may be effected by the environment, a number of research or investigative projects are recommended. These projects are listed in Figure 7.3.1, with an indication of the timeframe for completion and approximate cost. In this figure, the priority allocated to each project is reflected in the timeframe within which the project should be completed.

FIGURE 7.3.1

PROPOSED ENVIRONMENTAL RESEARCH

PROPOSED RESEARCH	YEARS 1 : 2 : 3 : 4 : 5	TOTAL COST (000,s)
a) Changing properties of ice.	----------	500
b) Ice regimes studies.	----------	500
c) Demonstration voyages/ice studies related directly to ship performance.	----------	1,000
d) Geographic distribution of icebergs in Baffin Bay.	----------	250
e) Variability of old ice movements.	----------	250
f) Mechanical properties of ice as it relates to design criteria.	----------	100
g) Investigation of the factors which influence good and bad ice years.	----------	200
h) Ridge data analysis.	----------	150
	TOTAL	2,950

7.3.3 Ship Operation

Based on the review of Arctic ship operations technology, a number of research or investigative projects are recommended. The projects are subdivided into the categories of 'safety', 'navigation', and 'communications', and are listed in Figure 7.3.2 with and indication of the timeframe for completion and approximate cost.

7.3.4 Ship Design

Based on the review of Arctic ship design technology, a number of research or investigative projects are recommended. The projects are subdivided into the categories of 'structures', 'hull design and performance', 'propulsion', and 'general outfit and auxiliary systems', and these projects are listed in Figures 7.3.3 to 7.3.6 with an indication of the timeframe for completion and approximate cost.

FIGURE 7.3.2

PROPOSED SHIP OPERATIONS RESEARCH

PROPOSED RESEARCH	YEARS 1 : 2 : 3 : 4 : 5	TOTAL COST (000,s)
<u>Safety</u>		
a) Lifesaving research:		
i) Field tests on lifesaving equipment in winter conditions.	---------. . .	250
ii) Field tests on personnel survival equipment and supplies in winter conditions.	---------. . .	200
iii) Field tests to assess the means of evacuation from Arctic ships.	---------. . .	150
b) Development of an Arctic survival training programme.	---------. . .	200
c) Field tests of shipboard firefighting equipment in very cold conditions.	---------. . .	250
<u>Navigation</u>		
a) Further development of SINSS.	---------. . .	500
b) Collection of radar data for small targets in sea clutter.	---------. . .	500
c) Detection of hazardous ice by use of improved searchlights or other light sources.	. ----------.	100
d) Field programmes to collect data for the further development of iceberg detection Sonars.	. ----------.	1,250
<u>Communications</u>		
a) Development of the capability to access the Anik D satillite.	. . ----------	500
b) Field testing of an HF modem.	. . ----------	75
	TOTAL	3,975

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FIGURE 7.3.3

PROPOSED HULL STRUCTURE RESEARCH

PROPOSED RESEARCH	YEARS 1 : 2 : 3 : 4 : 5	TOTAL COST (000,s)
a) Development of a methodology for plate design.	---------. . .	250
b) Develop a full understanding of framing behavior under ice loads and standardise the design methods.	---------. . .	250
c) Hull girder research:		
i) Field tests onboard Arctic ships.	----------	1,000
ii) Field tests to measure the ice response to ramming.	. ----------.	500
iii) Physical model testing of ship/ice interaction during ramming.	. ----------.	250
d) Development of fracture toughness criteria.	. ----------.	200
e) Field tests to validate the math modelling of the relationship between the air, water and structural temperatures.	. . . -----	100
f) Relationship between the fracture toughness and strain rate of steel.	. . . -----	150
g) Optimisation of weld metal material.	. . . -----	150
	TOTAL	2,850

FIGURE 7.3.4

PROPOSED HULL DESIGN AND PERFORMANCE RESEARCH

PROPOSED RESEARCH	YEARS 1 : 2 : 3 : 4 : 5	TOTAL COST (000,s)
a) Breakdown of the components of icebreaking resistance.	---------. . .	250
b) Development of an empirical level ice performance prediction system.	---------. . .	500
c) Development of hull design optimisation methodology.	---------. . .	500
d) Improvement in the scaling of model ice characteristics.	---------. . .	150
e) Development of a model ice strength indexer and a procedure to relate the indexed strength to hull shape.	----. . .	150
f) Field tests to measure full scale friction forces and a model test programme to simulate those forces.	---------. . .	200
g) Determine the difference between the hydrodynamic forces in clear water and in ice.	----. . .	150
h) Analysis of the available full scale data on ramming for various ships.	----------. .	100
i) Development of an understanding of the performance of ships in ridges.	----------. .	250
j) Development of a modified towing post for use during resistance or 'English' style propulsion model tests.	. ----------.	100
	TOTAL	2,350

FIGURE 7.3.5

PROPOSED PROPULSION RESEARCH

PROPOSED RESEARCH	YEARS 1	2	3	4	5	TOTAL COST ('000.s)
a) Development of propeller shafting design methodology.	----	.	.	.		75
b) A study of the operating problems of diesel engines in the Arctic.	----	.	.	.		75
c) A study to assess the problems of burning heavy fuel in the Arctic.	----	.	.	.		50
d) Investigate the icing of engine room air intakes on Arctic ships.	----	.	.	.		60
e) Development of design requirements for Arctic ship propellers.	----------	.	.			100
f) Investigate the over-thrust on the propulsion system due to ice loads on the propeller.	-----	.	.	.		60
g) Investigate the benefits of protection of the propeller from ice loads.	----------	.	.			200
h) Investigation of the effect of ice on shafting and sterntube bearings.	----------	.	.			100
i) Investigate the problems of prime mover displacement due to thrust bearing deflection under ice loads.	.	----------	.			75
j) Develop methods to protect gearing from overtorques.	----------	.	.			60
k) Investigate the limitations in the use of various shaft seals.	.	-----	.			50
l) Field tests to measure the reduction gear loading due to ice loads on the propeller.	----------	----------	----------			250
m) Identify the parameters which should be specified for Arctic ship gears.	.	.	-----			50
					TOTAL	1,205

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FIGURE 7.3.6

PROPOSED GENERAL OUTFIT AND AUXILIARY SYSTEM RESEARCH

PROPOSED RESEARCH	YEARS 1 : 2 : 3 : 4 : 5	TOTAL COST (000,s)
a) Develop means for the protection of deck machinery on Arctic ships.	----------	200
b) Field tests to measure mooring forces and assess material suitability.	----------	200
c) Steering gear research:	----	50
i) Means to protect the rudder from ice loads.	---------	150
ii) Field tests to measure the magnitude and influence of ice loads throughout the steering system.	---------	500
iii) Develop steering gear design requirements.	----------	100
d) Field tests to aid in the development of de-icing and anti-icing features.	---------	250
e) Hull coating research:		
i) Field tests to measure the operating conditions for low friction coatings.	---------	200
ii) Investigation of the hull areas where the ice impacts and abrasion occurs.	----------	75
f) Investigation of how noise and vibration can be reduced in accommodation spaces.	----------	50
	TOTAL	1,775

8. CONCLUSIONS

This report has resulted from an extensive review of Arctic Ship Technology. The work has covered the full range of; environment, ship operations and ship design. The state-of-the-art in each area has been identified as have the information deficiencies. A research programme has been proposed to address these deficiencies, having regard for the most likely future Arctic Shipping Scenarios.

To ensure that the work has been thorough, the project team was comprised of environmental scientists, ship operators and ship designers with an up to date understanding of Arctic Ship Technology. The principal objective was to produce a reference manual for designers, operators, regulators and researchers. The report is well structured and supported by extensive references to published literature, with special data sheets for the most important publications.

The proposed research programme is subdivided into the main sections of the report and detailed discussion is provided of each item along with an indication of cost, timeframe and priority. The programme spans five years with total proposed expenditures as follows:

Research Area	Cost 000's
Environment	2,950
Ship Operations	
- safety	1,050
- navigation	1,850
- communications	575
Ship Design	
- hull structure	2,850
- hull design and performance	2,350
- propulsion	1,205
- general outfit and auxiliary systems	1,775
	14,605

When compared to the cost of designing and constructing several Arctic resource etraction projects this level of research expenditure is a small fraction of one percent. The overall cost is low but the importance is high and the economic benefits can be demonstrated to be substantial.